INTERNATIONAL CONFERENCE ON TRAFFIC AND TRANSPORT ENGINEERING

ictte

ISBN 978-86-916153-3-8

Belgrade 2016

INTERNATIONAL CONFERENCE ON TRAFFIC AND TRANSPORT ENGINEERING

ICTTE

November 24-25, 2016
Belgrade, Serbia

- ICTTE BELGRADE 2016 -
PROCEEDINGS OF THE THIRD INTERNATIONAL CONFERENCE ON TRAFFIC AND TRANSPORT ENGINEERING

ICTTE Belgrade 2016 has been jointly organized by the City Net Scientific Research Center Ltd. Belgrade and University of Belgrade, Faculty of Transport and Traffic Engineering. ICTTE Belgrade 2016 has been co-hosted by the AIIT (Associazione Italiana per l'Ingegneria del Traffico e dei Trasporti) Research Center, Rome, Italy and UITP (International Association of Public Transport) and has been organized under the auspices of the Italian Society of Transportation Infrastructures (SIIV – Società Italiana di Infrastrutture Viarie). The conference is held in Belgrade, Serbia, from 24th to 25th November 2016.

The conference covers a wide range of topics related to traffic and transport engineering, with the aim of representing the importance of all modes of traffic and transport, especially the importance of improving these industries, and their compliance to one of the most significant principles nowadays, sustainable development. ICTTE Belgrade 2016 gathers researchers, scientists and engineers whose fields of interest are traffic and transport engineering, and should provide them a good platform for discussion, interactions and exchange of information and ideas. ICTTE Proceedings have been indexed within Thomson Reuters's CPCI – Conference Proceedings Citation Index accessed via Web of Science.

For publisher:	Prof. Dr Srećko Žeželj
Editor in Chief:	Assoc. Prof. Dr Olja Čokorilo
Publisher:	City Net Scientific Research Center Ltd. Belgrade Uzun Mirkova 10/I 11000 Belgrade, Serbia Phone: (+381 11) 30 91 261 Cell: (+381 63) 28 12 55 e-mail: office@city-net.rs / office@ijtte.com www.citynetsrc.com / www.ijtte.com
Print:	Odmori se Ltd. Makedonska 2 11080 Belgrade, Serbia
Year:	2016
Circulation:	250

ISBN 978-86-916153-3-8

CIP - Каталогизација у публикацији - Народна библиотека Србије, Београд

656.07(082)(0.034.2)
711.73(082)(0.034.2)

INTERNATIONAL Conference on Traffic and Transport Engineering (3 ; 2016 ; Beograd)
[Proceedings of the Third] International Conference on Traffic and Transport Engineering ICTTE, November 24-25, 2016 Belgrade, Serbia [Elektronski izvor] / [editor in chief Olja Čokorilo]. - Belgrade : City Net Scientific Research Center, 2016 (Belgrade : Odmori se). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 250. - Bibliografija uz svaki rad.

ISBN 978-86-916153-3-8

a) Саобраћај - Зборници b) Транспортни системи - Зборници c) Роба - Превоз - Зборници
COBISS.SR-ID 227197964

PREFACE

Each year billions of Euros are spent globally in order to develop, manufacture, operate and maintain transportation systems and vehicles. However, each of these processes begins with scientific research which contributes to modern life principles.

Paralleling the spurt of work on new transportation principles, there has been renewed attention to their influences on mobility, economy, safety, security, urban planning, pricing, environmental protection, etc.

Keeping in mind our main scientific gain - to learn, discover and spread our knowledge to the new generations, I would like to believe that International Conference on Traffic and Transport Engineering - ICTTE2016 has a new role not just to connect among ourselves or our institutions, but to encourage each of us to share the great knowledge and years of dedicated work.

Moreover, I would be sincerely proud if this journey via different modes of transportation could be replaced by communication and information flows through our scientific network.

This proceedings is a result of the work of over 200 researchers from more than 30 countries worldwide and I wish you pleasant reading of selected topics.

ICTTE 2016 Director

Prof. dr Olja Čokorilo

ORGANIZING SECRETARIAT

Olja Čokorilo, *Conference Director*
Faculty of Transport and Traffic Engineering, University of Belgrade, SRB

Ivana Čavka, *Conference Executive Coordinator*
Faculty of Transport and Traffic Engineering, University of Belgrade, SRB

Ivan Ivković, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Srećko Žeželj, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB

INTERNATIONAL SCIENTIFIC COMMITTEE

Gianluca Dell'Acqua, *Committee President*
Department of Civil, Construction and Environmental Engineering, University of Napoli Federico II, ITA

Ádám Török, Budapest University of Technology and Economics, Department of Transport Technology and Economics, HUN
Ali Payidar Akgüngör, Transportation Division, Kirikkale University, TUR
Ankit Gupta, Civil Engineering Department, Indian Institute of Technology (Banaras Hindu University) Varanasi, IND
Ariane Dupont-Kieffer, Department of Economics at University of Paris I Panthéon-Sorbonne, PHARE, FRA
Arvind **Kumar Shukla**, Civil Engineering Department, Institute of Engineering & Technology U.P., IND
Borna Abramović, Faculty of Transport and Traffic Sciences, University of Zagreb, CRO
Cesar Queiroz, Claret Consulting LLC, Washington D.C., USA
Chris Pringle, MILT, Transport & Tourism, Elsevier, GBR
Davide Lo Presti, University of Nottingham, Faculty of Engineering, GBR
Davor Vujanović, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Dragan Čišić, Department of Logistics and Management, Faculty of Maritime Studies, University of Rijeka, CRO
Dragana Macura, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Elen Twrdy, Faculty of Maritime Studies and Transport, University of Ljubljana, SLO
Essam Dabbour, Department of Civil Engineering, College of Engineering, Abu Dhabi University, UAE
Florin Nemtanu, Department of Transport Electronics and Telematics, Transport Faculty, Politehnica University of Bucharest, ROM
Francesc Xavier Martínez de Osés, Nautical Science and Engineering Department, Universitat Politècnica de Catalunya, ESP
Francesca Russo, Department of Civil, Construction and Environmental Engineering, University of Napoli Federico II, ITA
Francesco Abbondati, Department of Civil, Construction and Environmental Engineering, University of Napoli Federico II, ITA
Francesco Saverio Capaldo, Department of Civil, Construction and Environmental Engineering, University of Napoli Federico II, ITA
Goran Mladenović, Faculty of Civil Engineering, University of Belgrade, SRB
Ivan Ivković, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Ivan Sikora, School of Mathematics, Computer Science and Engineering, City University London, GBR
Jaroslav Matuška, Department of Transport Technology and Control, Jan Perner Transport Faculty, University of Pardubice, CZE
Kalaga Ramachandra Rao, Department of Civil Engineering, Indian Institute of Technology Delhi, IND
Laura Garach Morcillo, Department of Civil Engineering, University of Granada, ESP
Laura Mancini, Department of Civil, Construction and Environmental Engineering, University of Napoli Federico II, ITA
Lidia Żakowska, Department for Civil Engineering, Cracow University of Technology, POL
Manuela Esposito, Department of Civil, Construction and Environmental Engineering, University of Napoli Federico II, ITA
Marinella Silvana Giunta, Department of Civil Engineering, Energy, Environment and Materials, Mediterranea University of Reggio Calabria, ITA
Mario De Luca, Department of Civil, Construction and Environmental Engineering, University of Napoli Federico II, ITA
Milan Janić, Faculty of Civil Engineering and Geosciences, Department of Transport and Planning, Delft University of Technology, NED
Milica Šelmić, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Mirjana Bugarinović, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Mohammed Taleb Obaidat, Civil Engineering Department, Jordan University of Science and Technology, JOR
Momčilo Dobrodolac, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Muhammed Yasin Çodur, Erzurum Technical University, Engineering and Architecture Faculty, Department of Civil Engineering, TUR
Nebojša Bojović, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Nilanchal Patel, Department of Remote Sensing, Birla Institute of Technology Mesra (A Deemed University of UGC), IND
Olegas Prentkovskis, Vilnius Gediminas Technical University, LTU
Olja Čokorilo, Faculty of Transport and Traffic Engineering, University of Belgrade, SRB
Onder Turan, Anadolu University, Faculty of Aeronautics and Astronautics, TUR
Ozlem Sahin, Anadolu University, Faculty of Aeronautics and Astronautics, TUR
Qi-Zhou Hu, School of Automation, Nanjing University of Science and Technology, CHN
Renato Filjar, Faculty of Engineering & Faculty of Maritime Studies, University of Rijeka, CRO
Rob Konings, Delft University of Technology, NED
Salvatore Antonio Biancardo, Department of Civil, Construction and Environmental Engineering, University of Napoli Federico II, ITA
Sanja Steiner, Faculty of Transport and Traffic Sciences, University of Zagreb, CRO

CONTENTS

SESSION 15: TRANSPORT INFRASTRUCTURE AND INTELLIGENT TRANSPORT SYSTEMS

SESSION 16: TRANSPORT MODELING AND DECISION MAKING

INVITED PAPER

WEB GRAPH ANALYSIS OF THE AIR TRAFFIC SAFETY COMMUNITY

Miloš A. Kovačević[1]
[1] *University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, Belgrade, Serbia*

Abstract: The structure and properties of the web graph originating from the air traffic safety community could reveal many interesting relationships which exist between key organizations in the field. Therefore, an attempt is made to collect a representative sample of relevant web pages from different sources, by utilizing an intelligent software agent capable of recognizing the concept of a typical air traffic safety page. Starting from a seed set of thirty relevant pages, the agent collected nearly 200,000 on-topic pages and recorded the links between them. The analysis of the compiled graph detected the most relevant pages and sites, common linking patterns and popular keywords used for titles and links texts.

Keywords: web graph, focused crawling, air traffic safety.

1. Introduction

World Wide Web can be represented as a graph G in which vertices correspond to web pages and edges to hyperlinks defined with related URLs. G is a directional graph, since a hyperlink can be followed only in one direction. Investigating the properties of G could lead to many interesting applications, but probably the most important application is related to the Page Rank algorithm (Brin and Page 1998.). Page Rank is used by Google to calculate the relevance of pages retrieved as answers to a user query. In (Flake et al. 2002.), Web communities are defined as strongly interconnected pages speaking about the same topic. Authors discuss the possibility to extract the communities merely using the connectivity information stored in the graph. Obviously, linking patterns can reveal interesting relations between different organizations that are present on the Web, and can help in finding the most appropriate information sources. In this paper, the author tries to analyze the Air Traffic Safety (ATS) community from its presence on the Web. The analysis is performed by using sophisticated machine learning techniques (Mitchell 1997.) which enable the recognition of an ATS page in G, and a software system capable to record the existing links between such pages.

2. Topical web graph and focused crawling

Topical web graph G_T is a subgraph of G in which all nodes represent pages related to a certain topic T. In this paper, T represents the air traffic safety (ATS) thematic which includes aircraft operational safety, rescue and emergency services systems, traffic control, legal issues, R & D and others. The pages from T are distributed among different sources such as international and governmental bodies, professional associations, companies, educational institutions and blogs. In order to analyze G_T, one first needs to visit as many as possible pages from T, and to record the links between them. The construction of G_T is a very complex task for manual execution, since experts are not able to examine efficiently large portions of the everyday changing community. Therefore, an automatic approach is needed to systematically record G_T at any given point in time. In this research, a system for acquiring relevant data from the Web, and building the related G_T, is proposed and evaluated on the ATS pages. The system is based on a topic-specific automated crawler (Kovačević and Davidson 2008), which is capable of discovering on-topic pages, using the machine learning techniques.

A crawler is a software component designed to visit web pages by using the HTTP(S) protocol, and to save them in a database for further analyses. It performs the task by starting from a seed set of initial addresses and, following links that connect neighboring pages, collects as many pages as possible. A focused crawler fetches only the pages that belong to a specified topic (Chakrabarti et al. 1999) by exploiting the fact that the Web is a "social network", and that pages mostly reference similar pages (Davison 2000). Therefore, when a visited page is judged to be relevant, its links are followed too, otherwise not - see Figure 1. Focused crawlers are used in a variety of applications, such as vertical search engines (McCallum et al. 2000), competitive intelligence (Chen et al. 2002), and digital libraries (Pant et al. 2004; Qin et al. 2004). There are two main issues related to the design of a successful focused crawler: how to recognize whether a page is on topic or not, and how to reorder links extracted from on-topic pages in such a way that the crawler visits the more promising pages before potentially less relevant ones (Pant and Srinivasan 2005).

[1] Corresponding author: milos@grf.bg.ac.rs

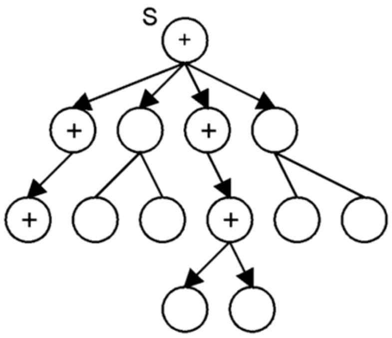


Fig. 1.
Focused crawler: starting from a seed page S, crawler follows only promising links while collecting on-topic pages (+). Links without arrows are not followed.

In the proposed system, a modification of Positive Examples Based Learning (PEBL) classifier (Yu et al. 2004) is used to determine if a visited page is on-topic, as it is described in the next section. Given a page *p*, PEBL outputs the probability of *p* belonging to the topic T. Despite the fact that relevant pages often point to other relevant pages, there exist situations in which one can reach the on-topic page by following a link from an off-topic page (i.e. a page from the air traffic community but not related to the safety issues, or a news agency page). Therefore, an approach is applied to take into account promising links from off-topic pages. Let *l* be a link contained in a page *p*. The proposed classifier outputs two probabilities: the probability of the whole *p* belonging to T, and the probability of the *l*'s anchor text and surrounding textual neighborhood being from T. Final decision for a link *l* to be followed is made after calculating the weighted sum of these two probabilities. Topical graph G_T is constructed by recording the paths traversed in the crawling session.
Focused crawlers periodically revisit already crawled places in order to detect new pages and sites in a community. Since the portion of the crawled Web is very small, the freshness of the acquired information is much better when compared to general purpose search engines like Google (Pant and Srinivasan 2005).

3. Detecting on-topic pages

Let + and – be the class labels assigned to all pages on the Web, such that pages from the topic T are labeled as + and all others as –. Suppose that there exists a function *f* which maps pages into the classes: $f(p) \rightarrow \{+, -\}$. Machine learning approach tries to find the representation of *f* from a small set of labeled examples, consisting of pages from both classes. Function *f* is called a classifier and the set of examples constitutes a training set. In order to learn the classifier one needs a suitable representation of each Web page. Commonly, the example pages are parsed in order to build a list of all different, extracted words. Classification vocabulary V is constructed from this list after the removal of non-informative words such as articles or numbers. Now, all the pages from the Web can be represented as vectors of word frequencies with respect to the vocabulary V (Salton 1989) - see Figure. 2a.

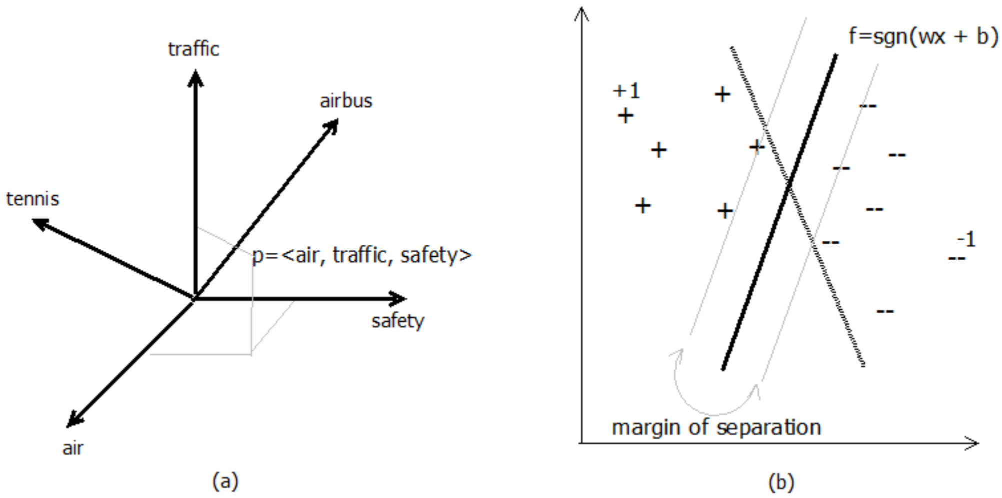


Fig. 2.
(a) Bag-of-words model: pages are points in the n-dimensional space of words, with normalised word frequencies as coordinates. (b) SVM: best separating hyperplane maximizes the margin of separation. The classification function assigns a label for an unseen instance **x** *according to its position with respect to the hyperplane (+1 above, or -1 under).*

A popular text classifier that is capable of learning the function *f* from the examples represented as vectors in the space of words, is called Support Vector Machines (SVM) (Vapnik 1995.). The essence of the basic SVM learning algorithm is described in Figure 2b. SVM tries to find a hyperplane which best separates the members of two different classes. The best separation is reached when the nearest instances from opposite classes are maximally distant (maximal margin of separation). There are two separating hyperplanes showed in Figure 2b. The hyperplane depicted with the gray, dotted line is not the appropriate one, since it lays in the middle of the very narrow margin. The best separating hyperplane $\mathbf{wx} + b = 0$ is situated in the middle of the maximal margin. Parameters **w** and *b* can be found in the learning process, which is formulated as an optimization problem on the training set. SVM is able to establish only a linear separation between classes, but is nevertheless suitable for web page classification due to high dimensional space of words (tens of thousands of words), in which classes become more linearly separable.

Original SVM is not suitable for building a focused crawler since it requires the examples from both positive (topic T) and negative class. While one can easily acquire certain number of pages from T, it is very difficult to model the negative class appropriately (everything on the Web which does not belong to T). Therefore, a Positive Examples Based Learning approach is applied in the proposed crawler, which utilizes the SVM algorithm, but instead of learning from positives and negatives, it constructs the classifier trained on a small set of positive (P) and a large set of unlabeled (U) examples. Unlabeled examples can be easily downloaded from the Web without the need to explicitly assign pages to certain classes. In this research, about 10.000 pages in English were downloaded from 15 top level categories of the Open Directory Project (http://www.dmoz.org).

PEBL is an iterative algorithm which tries in each iteration to increase the number of discovered negative examples from the unlabeled set U. In the first iteration, a list of strong positive words is formed. A word is a strong positive feature if its document frequency (number of documents in which it occurs) in P is higher than the corresponding document frequency in U. Pages from U which do not contain none of the strong positive features are considered to be strong negative examples. They are added to the initially empty set N^1 which is used, together with P, to train a classical two class SVM linear classifier. Such SVM is further applied on the $U \setminus N^1$ to extract additional negative examples. In the *k*-th iteration, N^k is constructed by adding newly found negatives to N^{k-1}, and the next SVM is trained on N^k and P. Algorithm terminates in the *n*-th iteration when there are no more negatives extracted from the remaining unlabeled pages. The decision classifier becomes the final SVM, trained on sets P and N^n.

The output of the classifier can be transformed into a class probability, by assuming that points located far away from the final SVM hyperplane have higher class probabilities than the closer ones. PEBL is sensitive to the number of positive examples, since more positives enable better estimates for initial, strong positive words.

4. Constructing ATS web graph

The proposed system for web pages acquisition and the associated topical graph construction is implemented as the author's private startup project (http://semanticjuice.com). In order to analyze the web graph of the ATS community, a classifier based on PEBL is trained on 30 initial examples, and the focused crawler is instructed to start from the seed set of 33 pages (Table 1). The examples are obtained from an independent expert in the field.

Table 1
Parameters of the ATS crawl

Examples	Seeds
http://www.skybrary.aero/index.php/Main_Page https://aviation-safety.net/ http://www.icao.int/safety/Pages/default.aspx http://www.ntsb.gov/investigations/AccidentReports/Pages/aviation.aspx http://www.easa.europa.eu/ http://www.eurocontrol.int/ https://www.ecac-ceac.org/safety http://www.jacdec.de/ http://www.planecrashinfo.com/ http://www.faa.gov/aircraft/safety/ http://www.faa.gov/airports/airport_safety/ http://www.iata.org/whatwedo/safety/pages/index.aspx http://www.iata.org http://www.flightsafety.org http://www.boeing.com/company/about-bca/aviation-safety.page http://www.airbus.com/company/aircraft-manufacture/quality-and-safety-first/?contentId=%5B_TABLE%3Att_content%3B_FIELD%3Auid%5D%2C&cHash=22935adfac92fcbbd4ba4e1441d13383 http://www.caa.co.uk/ http://www.cast-safety.org/ http://www.cast-safety.org/glossary.cfm http://essi.easa.europa.eu/index.html http://essi.easa.europa.eu/ehest/ http://essi.easa.europa.eu/egast/ http://essi.easa.europa.eu/ecast/ http://atc-news.com/ http://www.airsafe.com/	Examples URLs + http://www.icao.int/Pages/Links.aspx https://en.wikipedia.org/wiki/List_of_civil_aviation_authorities http://www.esasi.eu/aviation-links

https://ec.europa.eu/transport/modes/air/safety/safety-rules_en https://www.cranfield.ac.uk/courses/taught/safety-and-accident-investigation-air-transport https://www.eau.ac.ae/english/courses/postgraduate-studies/msc-aviation-safety.aspx http://www.aopa.org/training-and-safety/air-safety-institute http://www.aopa.org/training-and-safety/air-safety-institute/safety-spotlights	

After 24 hours of work, the system visited 1,625,453 pages and recognized 171,124 pages to be on-topic. The resulting ATS graph contained 171,124 vertices and 14,782,887 edges (links). There were 1,821,423 promising URLs known to the system, but the computing resources did not allow for further crawling (other commercial crawls were in progress).

5. Estimating classifier precision

After the crawling has been finished, the analysis is conducted to estimate the accuracy of the topical classifier. Since it is not convenient to verify whether each page *p* labeled as on-topic is correctly classified, a query is formulated to find if *p* contains words from two groups of keywords (*airplane*, *aircraft*, *aviation*, *helicopter*, *drone*, *pilot*, *airport*), and (*safe*, *safety*). The *p* is considered to be correctly classified if it contains at least one keyword from both groups. Table 2 shows the percentage of correctly classified on-topic pages during the progress of the crawl.

Table 2
Percentage of the correctly classified pages, after n collected on-topic pages

1,000	10,000	50,000	100,000	171,124
77 %	63 %	63 %	57 %	53 %

Slow decrease in classifier precision during the progress of the crawl can be partially explained as an effect of going further and further from the example pages, and slowly leaving the ATS community portion of the Web. As a final note on the estimated precision, the introduced verification rule is highly approximate, but appeared to be quite satisfactory when a random sample of 100 links is verified after the termination of the process (55 % correctly classified in the sample). The achieved performance of the PEBL classifier should be better if one increases the number of initial examples (Kovačević and Davidson 2008).

6. Community analysis

Due to limited space in the paper, a short, incomplete description of the ATS community graph is presented. Detailed properties of the graph can be found at https://www.semanticjuice.com/aviation-safety/. Please note that the reported analysis follows from the collected sample which is highly dependent to the initial set of examples.
Table 3, column two, lists the most important domains in the ATS community, according to the ranking function which combines relevance and popularity scores. Domain relevance is calculated as the average probability of an on-topic page being on-topic (the probabilistic output of the PEBL classifier). Domain popularity is proportional to the number of other relevant domains which link to the domain under consideration. Domains which are linked the most from other relevant domains are listed in the next column of Table 3. In addition, the graph memorizes who links to, for example, domain *cad.gov.rs*, revealing that Civil Aviation Directorate of Republic of Serbia should work more to increase the public awareness of its existence (last column). Interestingly, for the same query used to test the classifier precision, Google outputs the *aviation-safety.com* as the first result too.

Table 3
Domains stats (first fifteen from the highest to the lowest rank)

Importance	Most links from other relevant domains	Most links to *cad.gov.rs*
aviation-safety.net	faa.gov	skytamer.com
aviationweek.com	youtube.com	eurocontrol.int
nbaa.org	facebook.com	aviationbrowser.com
casa.gov.au	osha.gov	aviation-links.co.uk
faa.gov	europa.eu	stackexchange.com
nycaviation.com	wikipedia.org	
aopa.org	aopa.org	
airport-data.com	dot.gov	
jdasolutions.aero	cdc.gov	
airfleets.net	ntsb.gov	
skybrary.aero	icao.int	
askacfi.com	nsc.org	
universalweather.com	wordpress.com	
handbook.aero	nhtsa.gov	
aviationnews-online.com	cpsc.gov	

In Table 4, three different page stats from the topical graph are shown: the most referenced pages (authorities), the pages with the biggest number of outgoing links (hubs), and the most popular pages ranked according to the modification of the Google's Page Rank (Brin and Page 1998.).

Table 4
Pages stats (first fifteen from the highest to the lowest rank)

Authorities	Hubs	Page Rank
http://aviationweek.com/	http://centreforaviation.com/profiles/airports/	http://www.airports-worldwide.com/articles.html
http://www.equipmentworld.com/safety-watch/	http://products.ihs.com/Ohsis-SEO/HEALTHSAFETYEXECUTIVE.html	http://www.airports-worldwide.com/
http://www.faa.gov/	http://www.air-valid.co.uk/airlines-events/	http://www.wordtravels.com/Airports
http://www.carriermanagement.com/	http://www.skygeek.com/mcfarlane.html	http://www.free-photos.biz/photographs/transportation/photos_of_aircraft
http://theflyingengineer.com/	https://www.airportia.com/united-states/	http://www.domain-b.com/aero/reports.htm
https://travel.gc.ca/	http://www.dfwtower.com/library/	http://aviationweek.com/
http://www.theaviationwriter.com/	http://www.prokerala.com/travel/airports/united-states-of-america/	http://www.airnav.com/airports/
http://www.bangaloreaviation.com/	http://www.nrso.ntua.gr/	http://www.airnav.com/fuel/
http://www.aspireaviation.com/	http://centreforaviation.com/profiles/airlines/	http://airlinespoon.free.fr/_Airline_List.htm
https://www.zillow.com/refinance/fl/safety-harbor/	http://airportwebcams.net/airport-webcams-by-airport-type/	http://www.aviongoo.com/light_sport_aircraft/
http://aviation-safety.net/	http://aviation-safety.net/database/operator/airline-country.php?id=N	http://infracircle.vccircle.com/category/transportation/aviation/
http://www.safety-health-expo.co.uk/	http://www.domain-b.com/aero/reports.htm	http://www.businessair.com/calendar
http://www.aviationtoday.com/	http://www.theafricanaviationtribune.com/search/label/ACMI	http://www.businessair.com/aviation-links
http://www.airbus.com/	http://www.theafricanaviationtribune.com/search/label/IOSA	http://www.businessair.com/aviation-jobs
http://wordpress.org/	http://www.theafricanaviationtribune.com/2013/07/eu-black-list-whos-hot-whos-not-in.html	http://www.businessair.com/corporate-aviation

When performing the crawl, the proposed system recorded not just the links between pages, but the page titles and texts associated with the links. This is very important information if one wants to analyze how the owner of a site perceives the other site (organization). As an example, Table 5 lists fifteen links from *flightmemory.com* to *aviation-safety.net* containing the word *airbus* in a link text.

Table 5
Fifteen pages from flightmemory.com which point to aviation-safety.net using airbus in the related link texts

Pages pointing to *aviation-safety.net*	With *airbus* in the link text
www.flightmemory.com/encyclopedia/Airbus_A300.html	-airbus a300
www.flightmemory.com/encyclopedia/Airbus_A340.html	-accident description for airbus a340 313x f glzq
www.flightmemory.com/encyclopedia/Asiana_Airlines.html	-asn aircraft accident airbus a320 232 hl7762 hiroshima international airport hij
www.flightmemory.com/encyclopedia/Gulf_Air.html	-airbus a320 a40 ek accident record
www.flightmemory.com/encyclopedia/Airbus_A330.html	-asn aircraft accident description airbus a 330243 4r alf colombo bandaranayake international airport
www.flightmemory.com/encyclopedia/Gulf_Air.html	-airbus a320 a4o ek accident record graphic a40 ek flight path dervied from lat and long fdr parameters
www.flightmemory.com/encyclopedia/Airbus_A320.html	-airbus a320 occurrences
www.flightmemory.com/encyclopedia/Airbus_A330.html	-airbus a330 hull losses
www.flightmemory.com/encyclopedia/Airbus_A320.html	-airbus a320 hull loss occurrences
www.flightmemory.com/encyclopedia/Airbus_A330.html	-aircraft accident airbus a330 322 9m mkb kuala lumpur international airport kul
www.flightmemory.com/encyclopedia/Airbus_A330.html	-airbus a330 incidents
www.statemaster.com/encyclopedia/Airbus-A310	-asn aircraft accident airbus a 310 325 s2 ade dubai airport dxb
www.flightmemory.com/encyclopedia/Airbus_A330.html	-airbus a330 accident statistics
www.flightmemory.com/encyclopedia/Airbus_A300.html	-airbus a300c4 620 9k ahg mosul airport mos
www.flightmemory.com/encyclopedia/Airbus_A300.html	-airbus a300b2 1c f buae montpellier frejorgues airport mpl

7. Conclusion

In this paper, an analysis of the web presence of key air traffic safety organizations is presented. After collecting nearly 200,000 on-topic pages, starting from a seed set of 30 examples, the intelligent focused crawler constructed a web graph of the ATS community. The precision of the machine learning constructed classifier appeared to be nearly 60%, which can be further improved by adding more initial examples. The processing of the constructed topical graph revealed the most important sites and pages in the community. Topical graph can be used to detect linking patterns between organizations. The complete analyses can be found on http://semanticjuice.com.

References

Brin, S.; Page, L. 1998. The anatomy of a large-scale hyper textual web search engine, *Computer Networks*, 30: 107-117.

Chakrabarti, S.; van den Berg, M.; Dom, B. 1999. Focused crawling: A new approach to topic-specific web resource discovery, *Computer Networks*, 31(11-16): 1623-1640.

Chen, H.; Chau, M.; Zeng, D. 2002. CI spider: A tool for competitive intelligence on the web, *Decision Support Systems*, 34(1): 1-17.

Davison, B.D. 2000. Topical locality in the web. In *Proceedings of 23rd Annual Int. Conf. on Research and Development in Information Retrieval*, 272-279.

Flake, G.W.; Lawrence, S.; Giles, C.L.; Coetzee, F.M. 2002. Self organization and identification of Web communities, *IEEE Computer*, 35(3): 66-71.

Kovačević, M.; Davidson, C. 2008. Crawling the Construction Web – A Machine Learning Approach without Negative Examples, *Applied Artificial Intelligence*, 22(22): 459-482.

McCallum, A.; Nigam, K.; Rennie, J.; Seymore, K. 2000. Automating the construction of internet portals with machine learning, *Information Retrieval*, 3(2): 127-163.

Mitchell, T.M. 1997. *Machine Learning*, McGraw Hill, New York, USA.

Pant, G.; Tsioutsiouliklis, K.; Johnson, J.; Giles, C.L. 2004. Panorama: Extending digital libraries with topical crawlers. In *Proceedings of the 4th ACM/IEEE-CS Joint Conf. on Digital Libraries*. 142-150.

Pant, G.; Srinivasan, P. 2005. Learning to crawl: Comparing classification schemes. *ACM Trans. Inf. Syst. secur*., 23(4): 430-462.

Salton, G. 1989. *Automatic text processing*, Addison-Wesley, Reading, USA.

Vapnik, V. 1995. *The Nature of Statistical Learning Theory*, Springer, New York, USA.

Qin, J.; Zhou, Y.; Chau, M. 2004. Building domain-specific web collections for scientific digital libraries: A meta-search enhanced focused crawling method. In *Proceedings of the 4th ACM/IEEE-CS Joint Conf. on Digital Libraries*, 135-141.

Yu, H.; Han, J.; Chang, K. 2004. PEBL: Web page classification without negative examples, *IEEE Transactions on Knowledge and Data Engineering*, 16: 1-12.

SESSION 1: AIR TRAFFIC AND TRANSPORT RESEARCH AND INNOVATION

CONCEPTUAL ADVANCEMENTS FOR AN ADAPTIVE AUGMENTED VISION BASED ASSISTANCE SYSTEM FOR AIR TRAFFIC CONTROL TOWERS

Hejar Gürlük[1], Philipp B. Sinapius[2]
[1,2] Institute of Flight Guidance, Department of Controller Assistance, German Aerospace Center (DLR), Braunschweig, Germany

Abstract: This paper describes the enhancements of a novel concept of operations for future assistance systems for tower air traffic controllers developed by the Institute of Flight Guidance at the German Aerospace Centre (DLR). The concept envisions a wearable head up display that projects operational data into the air traffic controllers' outside view. Based on a multi-dimensional adaptive automation model the system monitors both the operational environment and the air traffic controllers' behaviour. The assistance system adapts the information presentation on the head up display accordingly following the premise to display the right (amount of) information at the right time. This paper presents further advancements of this concept. These are largely based on field observations and workshops conducted with controllers at two German air traffic control towers of mid-sized airports. The main aim of the workshops was to assess the importance of certain bits of information in relation to the traffic situation and environmental conditions. The key enhancements introduced in this paper comprise an information model determining the most relevant information for dynamic and static head up information presentation as well as an innovative adaptive radar label concept tailored to the current operational conditions in the control tower. Also several conceptual designs that were developed together with the controllers will be presented in this paper. As the results are based on expert opinions, the concept is close to the operational reality and promises to reduce the workload for air traffic controllers required for the search of information during nominal tower operations. The concept with its advancements serves as a base for on-going prototype implementations and simulation studies planned with air traffic controllers in the near future.

Keywords: air traffic control, tower, augmented vision, adaptive, assistance system.

1. Introduction

Air traffic controllers (ATCOs) ensure a safe, orderly and economic air traffic flow. ATCOs continuously have to evaluate new flight information or related information, and closely coordinate and communicate their efforts with other air traffic control units and stakeholders such as ground handling services. Tower ATCOs are in general responsible for the aerodrome traffic on a controlled aerodrome. Tower air traffic control operations can be referred to Tower Control (TC) and Ground Control (GC). In general, TC encompasses the handling of arriving and departing airborne traffic within the aerodrome control zone as well as traffic on runways. GC predominantly directs aircraft to and from the runway via taxiways and is responsible for the control of other aircraft and vehicular movement on the airport movement area. Both can require the dissemination of relevant information such as traffic, weather, equipment status, flight plans, revisions etc. (Ruffner, 2008).
Tower air traffic control requires a continuous monitoring and processing of numerous information sources. In view of today's tower controller working positions (CWP), they are typically characterized by a high number of distributed information and support systems referred to as "head down" displays. Often each of these widely distributed head down displays provides its own human machine interface (HMI) components and interaction devices. Additionally, ATCOs have to mentally merge the different information sources, including the outside view, in order to obtain adequate situational awareness. Altogether can potentially lead to higher workload in terms of prolonged times for information acquisition and analysis (Gürlük, 2016).
Apart from the head-down displays the main information source for tower ATCOs still remains the outside view referred to as "head up". The outside view is essential for tower operations in order to obtain the current aircraft position and maintain adequate situational awareness. However, a continuous transition from head up to head down which is an integral part of the controllers work in a tower environment can be quite critical for tower operations if head down times are prolonged and thus possibly lead to hazardous incidents as for instance runway incursions (Hilburn, 2004).

2. Theoretical Background and Motivation

One possible option to mitigate the above mentioned "head up vs. head down" problem could be an augmented vision solution projecting critical flight data onto the natural outside view of the tower ATCO. The integration of augmented data within the tower environment has become a research interest within the last years (Reisman, 2006; Bergner and Schmand, 2013; Hofmann et al., 2012). These systems however showed particularly deficits in regard of display ergonomics and user- and context sensitive information presentation. Typically information was displayed for all aircraft in the view of the head up display regardless of the ATCO's specific information needs. This causes information to overlap and hence to over-clutter the ATCO's primary field of view when there are several aircraft movements. Research showed that it would be also of particular interest for which aircraft in the ATCO's field of view which information has to be displayed that is relevant in the current situation (Schmand and Bergner, 2013). Research analysis also revealed,

[1] Corresponding author: hejar.guerluek@dlr.de

that no work has been published on state-of-the-art wearable augmented vision display technologies that allow both tailored information presentation and multi-user operations for tower air traffic controllers. Also the manipulation of augmented data has not been investigated yet.

In response to the described issues a novel concept for the display of augmented tower air traffic control data in combination with a multidimensional adaptation model was proposed by Gürlük (2016). Hereby, the information presentation is tailored to the ATCO's informational needs in dependence of the current user behaviour, task, environmental conditions and operational constraints. The concept which serves as the basis for the envisioned assistance system encompasses a multi-dimensional adaptive automation model that combines operator-based and context-based adaptation triggers. First, the system collects data via sensors and information systems in order to assess the operational context and operator behaviour (see Figure 1, left). The selection of the operator-based adaptation triggers such as speech recognition, eye-tracking and user input is based on the premise to consider sensors that are presumably operationally feasible within the airport tower environment. This requires unobtrusive sensors which are not attached to the body or even worse impair the mobility and comfort of the operator. For the context-based adaptation triggers the following data sources were selected: surveillance data from aerodrome surveillance and ground radar, flight plan data, environmental data (weather, wind, visibility conditions, etc.), and planning information derived from air traffic control (ATC) planning systems.

The assessment of the operational context and ATCO behaviour can then be used, in isolation or combination, to trigger the decision of which adaptations to select. The envisioned assistance system currently is limited to adaptations of the information content and interaction mode. Adaptation to information content is straightforward: the dynamic decluttering adaptations based on operator and/or context-based adaption rules are used to help the ATCO focus on only the most relevant information for the task at hand. When modifying the content, it is crucial to provide the ATCO with the information needed to successfully accomplish the work. The other adaptation, modification of interaction, comprises adaptations to the interaction style and interface features, e.g. visual or auditive information augmentation to direct the attention. As the ATCO represents the final decision authority, the ATCO can intervene and adapt the information according to his needs via user input whenever the display content needs to be updated, is not available, incomplete or not desired. This is why the proposed concept incorporates also the manipulation of augmented data (see figure 1, bottom right) and synchronization with head-down devices such as electronic flight strips (Gürlük, 2016). If the ATCO for example inputs given clearances into the electronic flight strips system, the clearance appears within the augmented labels as well. Particularly in early design phases the synchronization with head-down devices such as electronic flight strips must be provided to enable a smooth transition from status-quo systems towards new HMI concepts on one hand and also to help the ATCO to maintain adequate situational awareness in a user-accepted system (Ohneiser, 2016) on the other hand. The concept foresees also browsing through augmented data by means of interaction devices in order to select a specific target (see figure 1, bottom right). Finally the adaptive changes are then executed by the adaptive system if accepted by the ATCO or by user input via the human-machine interface. The control loop is closed by continuous monitoring of the trigger values described above by the automation for a continuous adaptation.

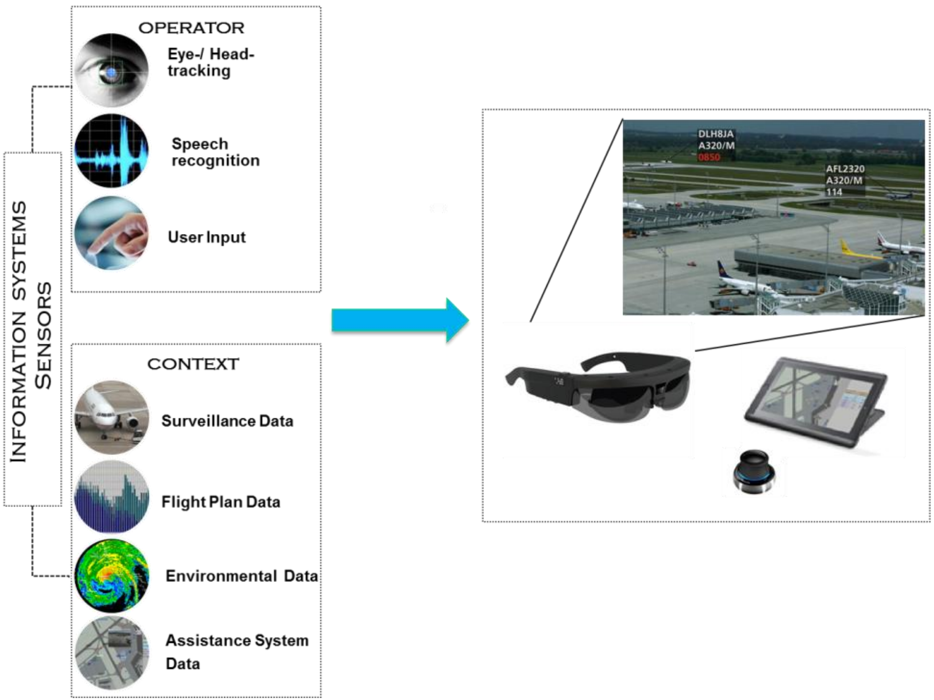


Fig. 1.

Simplified framework of the concept proposed by Gürlük (2016). The adaptive information management is based on information systems and sensors (left). Augmented traffic data is displayed on a wearable (right). Augmented data manipulation is enabled by interaction devices (bottom right)

The expected benefit of the described concept is an information presentation tailored to the individual ATCO informational needs and the specific operational context, hence resulting in a reduction of clutter and informational workload. The ATCOs can also spend more time working head up, thus benefits are also expected in the reduction of search times for information normally presented head down, increased runway safety and situational awareness (Gürlük, 2016).
The work presented in this paper is part of the DLR project Adaptive Controller Support Components (AdCoSCo), which investigates broadly the application of adaptive automation in combination with augmented vision and selected interaction technologies, e.g. automatic speech recognition for the support of air traffic controllers. In order to enrich the proposed concept two sites of the German air navigation service provider Deutsche Flugsicherung (DFS) have been visited. Task Analyses, field observations as well as structured interviews and workshops with tower ATCO have been conducted. The main results of these activities, an information model and adaptive radar label concept, are presented in this paper. The conceptual advancements in this paper focus mainly on context-based adaptation.

3. Method

In order to closely relate the concept with its multi-dimensional adaption model to the requirements of today's operation, a review of controller tasks was performed and interviews with ATCOs were conducted to determine their operational practices and their use of information systems. From these interviews, a model of information requirement (see section 4.1) in relation to the operational environment was derived which is the basis for an advanced concept design, in particular the adaptive radar label concept (see section 4.2).

3.1. Task Analyses

The task analyses were based on the manuals of operation for tower control in Germany. The manual (DFS, 2015) define high level and more concrete tasks for tower air traffic controllers:

- Control of flights operating under visual flight rules (VFR) that fly inside, leave or enter the control zone (CTR) unless under control of the approach control unit,
- Departing and arriving aircraft both under visual and instrument flight rules (IFR),
- Aircraft on ground in the vicinity of the runways.

The tasks are further detailed as follows:

- Observation of all aircraft, vehicle and personnel on the movement areas,
- Issuance of all necessary air traffic control clearances and instructions via radio telephony:
    - Clearance to enter the ctr,
    - Clearance to leave/cross the ctr,
    - Instructions to create a landing and departure sequence,
    - Instructions to line-up on the runway,
    - Take-off and landing clearances.
- Issuance of information for safe, orderly and expeditious operations:
    - Relevant local traffic information,
    - Relevant information about the aerodrome state,
    - Weather information.

Based on those pre-defined high-level tasks, semi-structured interviews were conducted with seven ATCOs at two tower facilities of the DFS. The interviews are helpful in order to better understand the information requirements for the completion of their tasks as well as the relative importance of the different sources of information and the timing of information presentation. As the time for the controller interview was limited, only the following five cardinal tasks for tower controllers were chosen for the interview guideline:

1. Surveillance of movement areas and the airspace (control zone),
2. Determination and control of the take-off sequence,
3. Determination and control of the landing sequence,
4. Take-off clearances,
5. Landing clearances.

For each of these five tasks, the following questions were discussed:

- Which information is required to perform the task?
- During which periods of time before and after the clearance is the information required?
- Is coordination required to perform this task?
- Which instructions have to be issued?
- Is there a difference between daytime and during night time operations?
- Is there a difference between high and during low visibility conditions?
- Do you see a potential to transfer the information to a head up display?

- Do you have any ideas how this situation can be displayed head up and how it can be supported by adaptive automation?

3.2. Field Observations

Parts of the on-site workshops were performed in the cab of the control towers located at the respective facilities. This allowed for an overview over the consoles with the different head down systems as well as a deeper insight into the work of the controllers. Questions and observations could be discussed on site with off-duty controllers, which allowed for an in-depth investigation of the work environment and information requirements of the controllers.

4. Results

In general, the interviews with the ATCOs revealed that the concept of the augmented vision assistance system with adaptive information management (Gürlük, 2016) could be beneficial for tower operations. According to the ATCOs opinion the amount of data and its adaptive information presentation must be carefully designed in order to avoid over-cluttering or produce even more severe problems that could affect operations. The controllers uttered many ideas in which augmented vision based adaptive automation could support them in their work. Their ideas are also reflected in the information model and adaptive label concept, which are presented subsequently.

4.1. Information Model

As a prerequisite for the overall concept design, particularly for the augmented adaptive labels, a model of information requirements for air traffic controllers was derived from the interviews and field observations. The model aims to describe the nature of the different pieces of information controllers require for their work in order to derive whether a piece of information should or should not be displayed in the head up display. The information required by air traffic controllers can be segmented into time critical, non-time critical information and general information.

4.1.1. Time-Critical Information

The first is only required during limited time windows, yet have to be accurate in this time window as they may be dynamically changing. Outside of these time windows, the information is not required. This information includes, but is not limited to:

- Wind direction, speed and gust values,
- Runway visual range (rvr) values (in reduced visibility conditions),
- Distance to go and ground speed for inbound aircraft.

This information is required irrespective of whether the movement is departing, arriving or flying locally.

4.1.2. Non-Time-Critical Information

The *non-time-critical* information usually pertains to certain flights. In a sense, it stays constant for the flight, yet is dynamic insofar as the flight progresses through the airport. Additionally, the controller has to track several flights at any given time and has to correctly attribute the information to each flight. This information includes, but is not limited to

- Callsign,
- Aircraft type,
- Slot times (for departures),
- Departure and destination aerodrome (for departures),
- Planned route (for departures),
- Altitude.

4.1.3. General Information

General information does only vary rarely or not at all. Controllers require this type of information to build and maintain their mental model, however once the information is received and acknowledged, it is not of immediate importance. These information includes, but is not limited to

- runway and airspace configuration
- layout and restrictions on departure procedures
- standing agreements with other air traffic control positions and units

For the design of an adaptive augmented vision system, it seems hence preferable to only display the data that is used the most frequently and/or data that changes dynamically. It was thus decided to choose information from the time-critical and non-time-critical category for the adaptive label concept.

4.2. Adaptive Label Concept

To support the controller, information shall be displayed in the head up display which can be grouped into two categories: information pertaining to individual aircraft or vehicles (e.g. position, callsign) and information valid for the entire airport (e.g. weather data). At the core of the concept are labels that are attached to aircraft in the outside view that convey additional data about the flight. The label type data representation was chosen to keep the look of the head up display close to the look of existing radar displays, in order to help controllers quickly transition to a head up working mode. To avoid clutter and provide the ATCO only with relevant flight data in dependence of the current operational context, a set of labels was developed. Only one label type per time is attached to each aircraft. Each label type conveys a slightly different set of information, tailored to the operational requirements of the controllers.

- **Visual marker:** Aircraft and vehicles are highlighted by suitable visual cue (box, dot or similar) in the outside view. This highlighting is however just a visual cue that an aircraft or vehicle is at that position and does not contain any further information.
- **Concerned label:** This label type attaches the following information to the aircraft: callsign, aircraft type and wake turbulence category.
- **Departure ground label:** For departing aircraft on ground, the label shows the following information adjacent to the highlighting box: callsign, aircraft type and wake turbulence category, departure route, calculated takeoff time (CTOT) if any
- **Departure air label:** Once departing aircraft are airborne, the data content shall be reduced to show callsign, aircraft type and wake turbulence category and the aircraft altitude
- **Arrival air label:** For arriving aircraft on final approach shows the following information adjacent to the highlighting cue: callsign, aircraft type and wake turbulence category, ground speed and distance to the threshold.
- **Arrival ground label:** Once arriving aircraft are on ground, the label displays the following information: callsign and scheduled parking position.

Fig. 2.
Visualization of the augmented label concept: DLH8JA with a departure ground label (left), aircraft with callsign AFL2320 with a concerned label. On the upper right a data block with critical data is displayed (UTC, wind data and QNH)

To satisfy the requirement of identifying air traffic transmitting on the frequency, a visual cue similar to a very high frequency direction finder (VDF) on a radar scope shall be provided to indicate from which direction the transmission is originating. To concatenate the information pertinent to the entire airport, the following data shall be included as overlay data block in the head up display for visual meteorological conditions (VMC):

- Wind data (direction, speed, and gusts),
- Air pressure value (qnh).

For inclement weather conditions, additional data shall be added to this data block:

- RVR values (touchdown, midpoint, rollout),
- Runway friction values.

4.3. Invocation Conditions

To trigger the changes between the labels, invocation conditions or triggers are defined. These triggers may be one or a set of several values or states measured by the adaptive system. If none of the invocation conditions of the other label types are met, no label is displayed.
The concerned label is invoked for a period of time (e.g. 30s) after the aircraft has been transferred by another controller (e.g. ground control) to the tower controller. This information could be derived from a flight strip system or (should it be available) an automated speech recognition system that detects the other controller's instructions. Hereby, this label serves as an announcement that this aircraft will most likely make radio contact in the near future.
The departure ground label is invoked when an aircraft is on ground, scheduled to depart and enters a predefined area on the airport where aircraft usually receive the take-off clearance. This label is displayed however for aircraft that are judged to be the next in the take-off sequence based on the sequence of aircraft on the taxiway, slot times and departure schedule information if available. This trigger is based on flight plan data, ground surveillance radar and departure schedule data if available. Example areas for this solution are depicted in figure 3: the green areas are marking the taxiways leading to the runway thresholds of the departure runways while the red area marks the areas where arriving aircraft will cross.

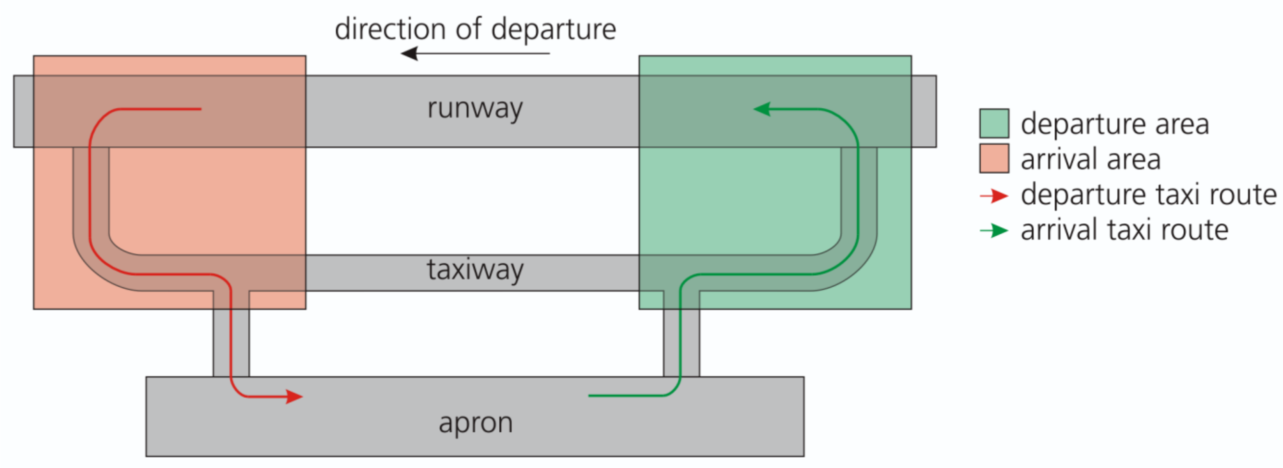


Fig. 3.
Invocation areas for adaptive labels

The departure air label will replace the departure ground label as soon as the system by means of aerodrome surveillance radar detects position information indicating a climb of the aircraft or by means of automatic speech recognition detecting the take-off clearance by the tower controller. The departure air label will display continuously until the aircraft reaches a defined altitude and/or distance from the field (e.g. 5000 feet and/or 8 NM). This requires again data from the radar system.
The arrival air label is presented for inbound aircraft on 10 NM final approach. The possible triggers are the groundspeed information and the flight plan. As for the departure ground label, this label is only displayed for the next inbound aircraft on final approach.
Once arriving aircraft pass a certain threshold speed, the arrival air label is replaced by the arrival ground label, a switching speed could be e.g. 40 knots. This label is presented until the speech recognition senses a handover of the tower controller to the ground controller or the flight strip is closed by the controller in the electronic flight strip (EFS) system.

5. Summary and Outlook

The paper describes the advancement of the concept proposed by Gürlük (2016) in the area of context based adaptive system design. Based on air traffic controllers' feedback during conducted interviews, a wearable head up display with adaptive information presentation seems beneficial with regard to information acquisition and information analysis times. This is the case when only aircraft are labeled with augmented flight data which are actually under the responsibility of the ATCO. Another aspect which promises to reduce controller workload and over-cluttering regards the tailoring of the information requirements to the current operational conditions and the ATCO's needs. As the concept is developed based on feedback and ideas of air traffic controllers to consider the operational reality and covers many of the requirements that the experts have. This concept is developed along the established theoretical frameworks for adaptive systems

(Dorneich & Feigh, 2012) and complies with recommended practises for automation employment in air traffic management (Inagaki, 2003).
While this concept takes into account actual operational requirements, there are still some open questions. Mainly, the concept does not take into account the state of the art of data collection and processing in the ATC environment. Technologies like automatic dependent surveillance (ADS), multilateration (MLAT) or ground radar as part of an advanced surface movement guidance and control system (A-SMGCS) are available today, however are not consistently available or even required for all relevant participants in aerodrome traffic (e.g. ground vehicles).
Future work on this topic should investigate the technical feasibility of augmented vision in the tower environment, especially the usability and display delay. These factors have so far precluded the introduction of augmented reality devices into the tower environment, although all studies indicate that it would be beneficial for the safety and efficiency of the work of tower air traffic controllers. Simulation studies will be conducted this year where parts of the multidimensional adaptation model as well as the augmentation of adaptive radar label into the outside view will be implemented and tested in collaboration with ATCO's from DFS.

Acknowledgements
The authors thank the ATCOs from DFS (DFS Deutsche Flugsicherung GmbH) Hamburg and Hannover for their collaboration and valuable inputs during the workshops.

Glossary

AdCosCo .... *Adaptive Controller Support Components*
ADS .... *automatic dependent surveillance*
A-SMGCS .... *advanced surface movement guidance and contol system*
ATC .... *air traffic control*
ATCO........ *air traffic controller*
CTOT .... *calculated takeoff time*
CTR........ *control zone*
CWP........ *controller working position*
DFS .... *Deutsche Flugsicherung*
EFS........ *Electronic Flight Strips*
GC........ *ground control*
HMI........ *human machine interface*
IFR .... *instrument flight rules*
MLAT .... *multilateration*
NM........ *nautical miles*
RVR .... *runway visual range*
TC .... *Tower contro*
VDF .... *VHF direction finder*
VFR........ *visual flight rules*
VMC .... *visual meteorological conditions*

References

Bergner, J.; Schmand, C. 2012. *Fortschrittliche Visualisierungssysteme für Fluglotsenarbeitsplätze*. In: Fortschrittliche Anzeigesysteme für die Fahrzeug- und Prozessführung, M. Grandt and S. Schmerwitz, Eds. : Deutsche Gesellschaft für Luft- und Raumfahrt, Bonn, Germany.
Deutsche Flugsicherung (DFS) GmbH 2015. *Manual of Operations, Air Traffic Services (MO-ATS), Eighth supplementary delivery*, Deutsche Flugsicherung, Langen (Hessen), Deutschland.
Feigh, K.; Dorneich, M.; Hayes, C. 2012. Toward a Characterization of Adaptive Systems: A Framework for Researchers and System Designers, *The Journal of the Human Factors and Ergonomics Society*, 54(6):1008-1024.
Gürlük, H. 2016. Concept of an Adaptive Augmented Vision Based Assistance System for Air Traffic Control Towers. In *Proceedings of the Digital Avionics System Conference*.
Hilburn, B.,2004. *Head Down Time in Aerodrome Operations: A Scope Study*, Center for Human Performance Research, Den Haag, Netherlands.
Hofmann, T.; König, C.; Bruder, R.; Bergner, J. 2012. How to reduce workload – augmented reality to ease the work of air traffic controllers, *Work*, 41(suppl 1): 1168-1173.
Inagaki, T., 2003. *Adaptive Automation: Sharing and Trading of Control*, In Hollnagel E. (Ed.), The Handbook of Cognitive Task Design, CRC Press, Boca Raton FL, U.S.A.
International Civil Aviation Organisation (ICAO). 2001, *Procedures for Air Navigation Services, Air Traffic Management (PANS-ATM)*, Fourteenth Edition, ICAO, Montreal, Quebec, Canada.
Ohneiser, O. 2016. *Improved User Acceptance During Stepwise Air Traffic Control Display Functionality Introduction*. In: Advances in Human Aspects of Transportation, Proceedings of the AHFE 2016, International Conference on Human Factors in Transportation, Stanton, N.A.; Landry, S.; Di Bacchiarico, G.; Vallicelli, A. (Eds.).

Peterson, S.; Axholt, M.; Ellis, S.R. 2008. *Managing Visual Clutter: A Generalized Technique for Label Segregation using Stereoscopic Disparity*, IEEE Virtual Reality, Reno, Nevada, U.S.A.
Reisman, R. Brown, D. 2006. Design of Augmented Reality Tools for Air Traffic Control Towers. In *Proceedings of the 6th AIAA Aviation Technology, Integration and Operations Conference*.
Ruffner, R.W.; Fulbrook, J.E. 2007. *Usability Considerations for a Tower Controller Near-Eye Augmented Reality Display*. In *Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting*.
Wickens, C.; Mayor, A.; Parasuraman, R.; McGee, J. 1998. *The future of Air Traffic Control: Human Operators and Automation*, National Academies Press, Washington D.C., U.S.A.

AN ECONOMETRIC ANALYSIS OF AIR TRAVEL DEMAND IN MOROCCO

Elmostafa Erraitab[1], Ahmed Hefnaoui[2], Mohammed Moutmihi[3]
[1,2,3] *Hassan II University, Faculty of Economic, Legal and Social Sciences, Mohammedia, Morocco*

Abstract: Given the importance of the air traffic analysis both for airlines and civil aviation authorities, the main aim of this paper is to develop an econometric model to analyze, assess and forecast the air travel demand in Morocco. To select the relevant variables, the all possible regression procedure was conducted. The model containing price index consumer, the gross national product, household final consumption per capita and international tourist's arrivals is the most appropriate model to represent the demand for air travel in Morocco.

Keywords: air travel demand, modeling air travel demand, all possible regression procedure, Morocco.

1. Introduction

Air travel demand modeling is a major determinant of airport planning. In fact, forecasting errors of air travel demand can be very expansive. Underestimate the air traffic demand can cause airport facilities congestion, increasing wait time and inadequate airport facilities. In the same time, overestimate the air traffic demand can induce serious financial problems for airport authorities. Air travel market analysis allows airlines to rationalize its human and financial resources and estimate future needs for recruitment and training manpower. Moreover, air travel market analysis allows airlines to assess objectively the current and future air travel demand by destinations and routes.

Over the period 1970-2000, air traffic has been trending regular evolution. However, once Moroccan government conducted a voluntary policy of air service liberalization, air passenger traffic recorded an average annual growth rate of 9% over the period 2005-2012. Indeed of air traffic increase, the policy of air service liberalization has reconfigured the Moroccan air travel market, there was a massive affluence of low cost carriers (LCC) and diversification of flight supply, as a consequence, the number of low cost European companies' weekly frequencies in the Moroccan market, rose from 600 in 2003 to 960 frequencies in 2009. This increased supply flights require a similar increase in airport facilities. Such a rapidly increase on aviation demand requires significantly accurate tools for short-term and long-term forecasting. Thus, the main purpose of this paper is to develop an econometric model that not only predict traffic but also determine the impact of changes within the economic environment on traffic.

This paper is organized as follows. Section 2 provide the literature review and section 3 presents data source used to analyze and develop an econometric model for air travel demand in morocco. Section 4 describes the chronology of the air traffic development in Morocco. Section 5 presents the determinants of air travel demand in Morocco while the sixth section display a descriptive analysis based on matrix correlation. Section 7 section describes the base model development. Base model run results is provided and commented in section 8. Finally in section 9, conclude the paper.

2. Literature review

The rapid growth of global air traffic has attracted the attention of many researchers and academics in the period 1970-2012, global air passenger traffic achieved an average annual growth rate of 5.4% (The World Bank IBRD-IDA). Studies that explore the air traffic demand has emerged strongly over the past four decades, and an abundant literature dealing determinants of air traffic demand has emerged.

There are several methods to model the air travel demand, ranging from methods base on time series, which can be summarized in two approaches, Box&Jenkins (1976) univariate approach and multivariate approach based on VAR and VECM, until approach based on econometric modelling. Time series power certainly has a strong predictive power, especially in short term, but are limited by their inability to determine the causes of changes in the explanatory variables. They cannot, for example, quantify the impact of rising income on the air travel demand. This question requires the specification and development of an econometric model that links changes in traffic demand with other relevant variables.

The study led by (Jung & Fujii, 1976) is considered one of the pioneering works in terms of estimating the price elasticity of air travel demand, however, this results are significant but not reliable for the following reason : The authors did not consider the differences from one trip to another; in fact, the price elasticity of demand for air travel for a passenger who wants to spend his weekend in another city is not the same as if he has to travel for business. This is confirmed by a recent study by (Callaghan & Tol, 2013) where the travel pattern case is price inelastic.

According to (Lewis & Mitchel, 1990), the quality can be defined as: 'To what extent service fulfills or exceeds the needs and expectations of consumers. Indeed, the quality of air service is an important factor for modeling the air travel demand, this factor was still ignored at several studies that aim to model the air travel demand. (Spence, 1975, cited by ((Ippolito, 1981)), considers that this variable is the key element of product differentiation. Despite the theoretical interest of the variables that represent the level of air traffic services, empirical models for modeling the demand for air passenger traffic have generally assumed that demand is insensitive to the air level service quality (example (De Vany,

[1] Corresponding author: m.raitab@gmail.com

1974). (Jung & Fujii, 1976). In 1975 (De Vany, 1975) caught the omission of air service quality in his model (1975), he integrated flight frequency as an indicator which can reflect the quality of service, although the empirical results for the variable frequency of flights were unsatisfactory, but this study has the merit of including the variable quality of service as a determinant of air travel demand. To take into account the variable quality of service (Ippolito, 1981) has specified the following model:

$$Q = A\exp(bF^2)N^{\beta}\left[(Q+Y)/S\right]^{\alpha} \tag{1}$$

Where; Q represents the origin/destination demand, Y passengers in transit, N flight frequencies, (Q + Y) / S is load factor and S is the average size of aircraft (the number of seats). The estimation results of equation 1 are compatible with the assumptions given by (Ippolito, 1981), the empirical results show that the demand for air travel is positively related to frequency of flights and negatively to load factor. However, the study results (Ippolito, 1981) come from a relatively small sample and carefully chosen to eliminate the theoretical and empirical problems, hence, the study results are related to these study assumptions.

In order to detect the determinants of domestic air traffic in the case of Saudi Arabia, (Abdullah O, Seraj, & Sajjad, 2000) used the technique of stepwise regression to find the best econometric model of the air traffic demand. The authors split the income into several categories; oil-GDP, Private Non-oil GDP, Government Non-oil GDP and total Non-oil GDP. They found that the model containing the explanatory variables as population size and total spending is the appropriate model to explain the demand for domestic air traffic in Saudi Arabia. Neither aggregate income nor any of its components were significantly explanatory of demand for international air travel in Saudi Arabia.

(Alperovich & Machnes, 1994) used permanent rather than current income as relevant variable which determines the demand for international air travel demand, the authors have shown that the main source of misspecification for last studies is the omission of variables representing the wealth of the consumer. The authors fond that demand for air travel out of Israel is price-inelastic and income-elastic, the results of their study support the fundamental assumption that the wealth of consumers is the key determinant of demand for air travel. The authors divided the consumers' wealth in two categories; financial and non financial assets. They argue that an aggregate income variable which combines income from different sources may be inadequate, since propensity to travel may be different according to the source of income. The main innovation of this paper is that ((Alperovich & Machnes, 1994) found that wealth variables display the anticipated positive signs and highly significant. Thus, the demand for air travel depends on consumer wealth and not only the current income.

In order to evaluate the economic impacts of permitting charter flights on tourism in Israel, (Haitovsky, Salomon, & Silman, 1987) have specified a two-equation model, one for overall tourism demand and the other for tourism demand addressed to scheduled flights. The resulting model has shown that regular flights demand is price-elastic in the presence of charter flights, that being said, the permitting of charter flights induces a fall in air fares of regular flights as a result of competition, and this indirectly promotes tourism in the countries that liberalize charter flights.

3. Data source

The data used to estimate the model have been taken from different sources. Data on Moroccan air travel are from Moroccan civil aviation authority database. The data on Moroccan social and economic characteristics that could affect demand for air traffic were taken from World Bank collection of development indicators (The World Bank IBRD-IDA).

4. Moroccan air travel developments

The geographical location and socio-political stability in Morocco, are considered as a significant factors to an important air traffic growth. Morocco is the first North African and seventh African country, with whom the United States signed an open skies agreement since 2002, in addition, indeed, in 2006, Morocco has signed with the European Union an open sky agreement, it was the first of its kind among the agreements between the European Union countries and non-EU countries.

Following the voluntary policy of air service liberalization conducted by the Moroccan government, the volume of air traffic passenger has increased from 6.7 million passengers in 2002 to 7.7 million passengers in 2006 and 15.2 million in 2012, realizing an average annual growth rate of 9% over the 2004-2012 period.

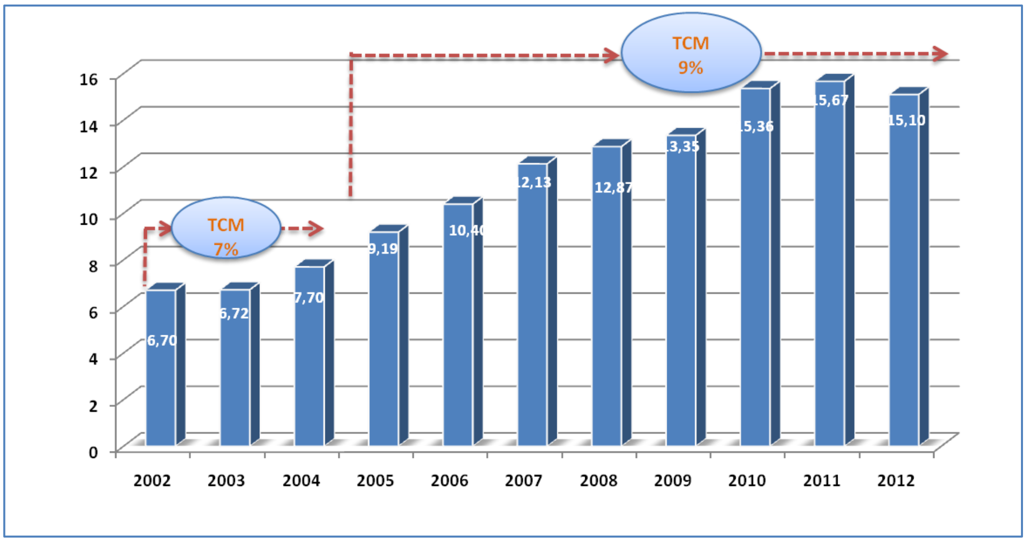


Fig. 1.
Air passenger traffic evolution over the 2002 à 2012 period
Source: Author's calculations based on Moroccan Civil Aviation Authority data.

Airlines have strongly increased their supply since 2003, all types of airlines together, they have increased the seat supply over the period 2003-2009 by 1.685 additional monthly frequencies.

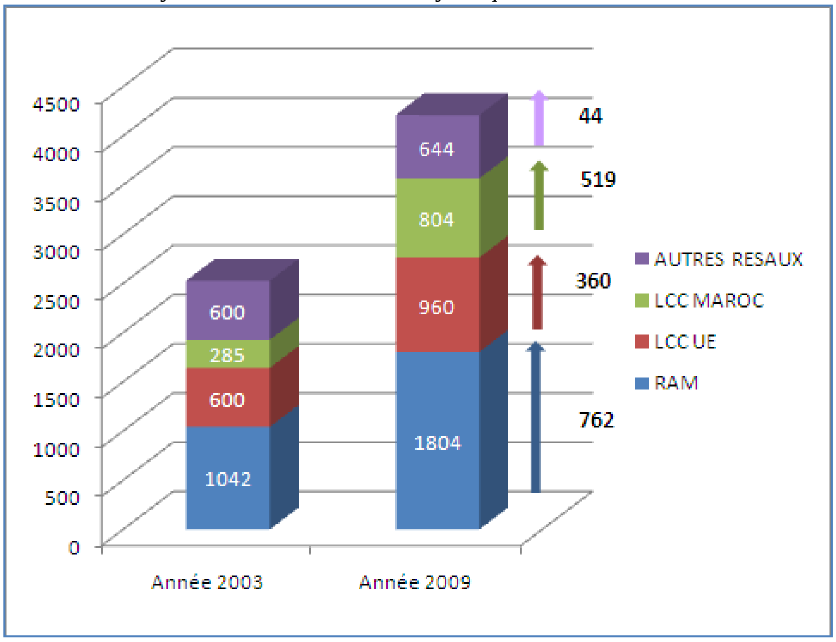


Fig. 2.
Supply growth of the Airlines that serve Moroccan air travel market
Source: Author's calculations based on OAG data, may 2003-2009.

Taking advantage of the open sky agreement signed between Morocco and the EU in 2006, several low-cost airlines have begun to serve the Moroccan destination. Thus, the European low cost carriers alone have increased their monthly frequencies of 360 additional frequencies between 2003 and 2006, in turn, followed the trend, the Moroccan LCC increased their monthly frequencies of 519 frequencies over same period.

5. The determinants of air travel demand in Morocco

The literature review allowed us to identify several factors that impact the demand for air travel, these factors can be summarized into two categories; The first affecting air transport supply and second affect demand side.
The factors that affect the air transport supply sides include regulatory framework, airline strategy in terms of number and frequency distribution over the day and over the week, the level of service quality in terminal and during the flight, infrastructure capability and competition from the other transportation modes.
Factors that impact the demand sides of air travel include household wealth (Alperovich & Machnes, 1994), the population size and total expenditure (Abdullah O, Seraj, & Sajjad, 2000) and the purpose of travel (De Vany, 1974).
The examination of literature review allowed us to select a list of air travel demand explanatory variables.

Modeling air travel demand in morocco will enable us to decide on the significance of each variable. Before starting the conception and estimating the econometric model, we begin with a correlation analysis of the used variables list.

5.1. Correlation matrix analysis

Table 1
Correlation matrix of the variables considered to explain air travel demand in Morocco

	PAX	GDPC	CPI	EGS	FCE	FDI	FF	GNI	HFCEPC	ITEP	ITET	ITNA	ITR
PAX	1	0,96	0,97	0,92	0,88	0,68	0,94	0,92	0,97	0,94	0,98	0,98	0,95
GDPC		1	0,99	0,95	0,85	0,77	0,96	0,97	0,99	0,96	0,96	0,99	0,97
CPI			1	0,96	0,88	0,76	0,97	0,97	0,99	0,97	0,97	0,99	0,97
EGS				1	0,85	0,81	0,95	0,95	0,93	0,95	0,89	0,95	0,98
FCE					1	0,65	0,87	0,90	0,84	0,87	0,87	0,90	0,87
FDI						1	0,70	0,77	0,76	0,77	0,69	0,73	0,84
FF							1	0,94	0,95	0,94	0,93	0,96	0,95
GNI								1	0,95	0,94	0,92	0,97	0,95
HFCEPC									1	0,96	0,98	0,98	0,96
ITEP										1	0,96	0,95	0,96
ITET											1	0,97	0,93
ITNA												1	0,96
ITR													1

Where GDPC : GDP per capita (constant 2005 US$), CPI: Consumer price index (2005 = 100), EGS: Exports of goods and services (constant 2005 US$), FCE: Final consumption expenditure (constant LCU), FDI : Foreign direct investment, net inflows (BoP, current US$), FF : Flight Frequency, GNI : HFCEPC : Household final consumption expenditure per capita (constant 2005 US$), ITEP : International tourism, expenditures for passenger transport items (current US$), ITET : International tourism, expenditures for travel items (current US$), ITNA : International tourism, number of arrivals, ITR : International tourism, receipts (current US$).

The correlation matrix shows that there is a high correlation between on the one hand, the consumer price index Household final consumption expenditure per capita, tourist spending, the number of international tourist arrivals and air traffic on the other.

One can observe that there is a strong correlation between the regressors variables and the dependent variable, it is a sign of collinearity presumption between independent variables. The presence of collinearity between the independent variables induces an increase of some estimated coefficients variance, instability of least squares coefficients estimator, and in case of perfect collinearity, the X'X matrix of regressors is singular, therefore it would be impossible to estimate the coefficients. Considering the problems that can cause the presence of collinearity phenomenon between the regressor variables, we must first check its presence and provide a procedure to treat it.

Farrar and Glauber test allows detecting the presence of collinearity. Appendix 1 gives program details for calculating the Farrar and Glauber test in Eviews.

According to the test results, it was found that the calculated chi-square is greater than the theoretical chi-square, $\chi_c^2 > \chi_{th}^2$,in this case we reject the null hypothesis H0 of no collinearity and alternative hypothesis H1 is accepted, there is a collinearity presumption among explanatory variables for air travel demand in Morocco.

As mentioned above, when there is an exact linear relationship between two or more explanatory variables, the linear regression equation becomes insoluble, that being said, one should keep only one of the explanatory variables among those that are perfectly correlated. This kind of collinearity treatment is especially true in cases where the correlated variables represent the same reality, when deleting one or several collinear variables, the remaining variable capture the effect of other removed variables.

5.2. Base model development

To find the right mix of explanatory variables, the all possible regression procedure for selecting independent variables was conducted (the detailed procedure program in Eviews is in Appendix 2). The procedure is to calculate all possible regressions or (2^k-1) regressions, in our case; we have to estimate 4095 models. Among 4095 models, we have to choose the appropriate model. The criteria for selecting the right model are the following:

a) All of the model coefficients must be significantly different to 0 and ,
b) The appropriate model must have the highest R^2.

The procedure of selecting the relevant variables shows that the best model is as follows:

$$Y_t' = 11818357.89 - 168393.3848 * x_{2t} - 1.975783646e-005 * x_{7t} + 7502.938943 * x_{8t} + 2.624283968 * x_{11t}$$
$$(-2,30) \quad (-4,66) \quad (2,94) \quad (8,02) \qquad (2)$$

Adjested $R^2 = 0.990964$

The values in parentheses represent the t-statistics of estimated parameters.
The R-squared (R^2), which can be interpreted as the fraction of the variance of the dependent variable explained by the independent variables, shows that there is a high linear relationship between air passenger demand in Morocco and the relevant variables chosen by the procedure (appendix 2), indeed, the F-statistic p-value, which is the marginal significance level of the F-test, is less than the significance level ($\alpha = 5\%$), so we reject the null hypothesis that all of the regression coefficients are zero.
Generally, when the time series are used, there is always a risk of falling into the error serial correlation phenomena when model is estimated by the OLS estimator. Therefore, before using the estimated model for statistic inference (eg, statistical hypothesis tests and projections), we should generally examine the residuals for evidence of serial correlation. Generally, according to ((Johnston & DiNardo, 1997), with 50 observations or more, and only a few independent variables, a DW statistic below about 1.5 is a strong indication of serial correlation of positive first order serial correlation.

Table 2
Correlogram of residual squared

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
. *| . |	. *| . |	1	-0.111	-0.111	0.2469	0.619
. *| . |	. *| . |	2	-0.153	-0.167	0.7515	0.687
. **| . |	. **| . |	3	-0.191	-0.239	1.5954	0.660
. *| . |	. **| . |	4	-0.107	-0.217	1.8816	0.758
. |***. |	. |** . |	5	0.343	0.240	5.0517	0.410
. *| . |	. *| . |	6	-0.122	-0.152	5.4901	0.483
. | . |	. *| . |	7	-0.052	-0.059	5.5784	0.590
. | . |	. | . |	8	-0.029	0.021	5.6089	0.691
. | . |	. | . |	9	0.000	0.011	5.6089	0.778
. | . |	. *| . |	10	0.000	-0.175	5.6089	0.847

Source: Author's calculations based on OAG data, world bank indicators database and Moroccan civil aviation authority database.

The correlogram for the first 10 lags from equation (2) does not show a significant serial correlation in the residuals. This result is confirmed by the Breusch-Godfrey LM test for serial correlation of residuals.

Table 1
Test Breusch-Godfrey Serial correlation LM Test

F-statistic	0.088754	Probability	0.915784
Obs*R-squared	0.296499	Probability	0.862216

Source : Author's calculations based on OAG data, world bank indicators database and Moroccan civil aviation authority database

The test does not reject the hypothesis of no serial correlation up to order two, The p-value of F-statistic and Obs* R-squared is well above the threshold of significance α 5%.

6. Results comment

By looking into the results of regression analysis of equation (2), it's found that variable X_2, which represents the effect of Consumer price index in Morocco, - holding other thing the same, has a negative and significant effect on air travel demand in Morocco. As such, the Consumer price index reflects changes in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Laspeyres formula is generally used. The consumer price index is usually calculated based on periodic surveys of price basket consumer. As shown in the regression results of equation (2), as consumer price index goes up by one percentage point, on the average, demand for air travel down by 16.8 million passengers. This result is consistent with those found by (Alperovich & Machnes, 1994), which showed that the air travel demand depends on the consumer total wealth. The

inflation increase, as measured by consumer price index, increases artificially the basket price of goods and services purchased by a standard consumer, as a result, the consumer wealth, especially the current income, is modified.
Gross National Income (GNI), represented by the variable X_7, GNP under the old appellation, which represents the sum of value added produced by all residents plus any taxes product (less subsidies) not included in the production valorization, plus net receipts of primary incomes (compensation of employees and property income) from abroad. In other words, this variable is the sum of value added produced by national, whether in the country or abroad. According to the Moroccan tourism observatory, almost 95% of the air passengers are foreign tourists or the Moroccan living abroad. Therefore, it seems that the air travel demand in Morocco is influenced much more by macroeconomic aggregates emitting countries tourists than by economic fundamentals of the national economy. Although the GNP variable is significantly different from 0, his impact is very small, its coefficient does not exceed the value of 0.0000198.
Household final consumption expenditure per capita, represented by the variable X_8, have a positive and significant coefficient, the t-Student statistic value of his coefficient is 2.94, meaning that true X_8 coefficient is different from 0. This variable captures the effect of Household final consumption expenditure per capita, represented by the market value of all goods and services, including durable products (cars, washing machines, and home computers), purchased by households. In other words, the evolution of this variable reflects the standard of living of households, an increase in final consumption expenditure of households indicates an increase in household wealth. The X_8 coefficient sign is consistent with those found by (Schafer & David G, 2000), indicating that as far as personal income tends to increase, the people mobility increases accordingly by turning to other faster and more expensive modes of transportation. Thus, our results are consistent with what we found in the literature review on the air travel demand, the travelers mobility depends strongly on the passenger wealth. Nevertheless, the impact of this variable is a handle with care, its impact is very small, as X_8 goes up by one percentage point, - holding other thing the same, demand for air travel increased only by 0,7 million passengers. This confirms what we have said above, the air travel demand in Morocco largely come from international tourists and Moroccan living abroad.
The X_{11} variable, represents the international tourism, number of arrivals. This variable include international inbound tourists visiting Morocco, ie, the number of tourists who travel to Morocco for a period not exceeding 12 months and whose main purpose in visiting is other than an activity remunerated from within the country visited. Under this definition, the Moroccan living abroad are also considered as foreign tourists.
The X_{11} variable has positive and strongly significant coefficient, this result is in line with those found by (Haitovsky, Salomon, & Silman, 1987), which concluded that the liberalization of charter flights in Israel, due to generation effect, forces scheduled air fares down and encourages improvement in the level of service; thus it indirectly favours tourism to countries permitting charter flights. Passengers on business trips or for other non-tourism purposes are price insensitive, but leisure purpose passengers are highly price sensitive.
The Moroccan government has adopted a deliberate policy of air service liberalization, it creates more competition between airlines, and such competition is played primarily on air fares. The introduction of low cost carriers in Moroccan air travel market induced lower air fares, increasing flight supply and diversification of destinations.

7. Conclusion

In this paper, an attempt is made to develop and estimate an econometric model explaining the air travel demand in morocco. The econometric model will be used as a tool to analyze and forecast the air travel demand, through establishing statistical relationship between selected demand-influencing factors and the corresponding level of traffic in morocco. In order to selecting the relevant variables, initially, we used correlation analysis, and then, we used a procedure that estimates all possible variables combinations and then choose between them the best model that satisfies the constraints required by the procedure.
We find that the model containing price index consumer, the gross national product, household final consumption per capita and international tourists arrivals is the best model. Thus, it seems that air travel demand in Morocco is dependent of socio-economic characteristics of transmitter States tourists.
The Moroccan civil aviation authorities and airlines, who want to deserve the Moroccan air travel market, can be based on this model to assess and predict the air travel demand in Morocco.

Annexes

Annexe 1 : Farrar and Glauber test program in Eviews

```
equation eq2.ls  y c x1 x2 x3  x4 x5 x6 x7 x8 x9 x10 x11 x12
group mygroup1  x1 x2 x3 x4 x5 x6 x7 x8 x9 x10 x11 x12
mygroup1.cor
matrix mat=@cor(mygroup1)
scalar dt = @det(mat)
scalar khi = -(@regobs-1-(2*@ncoef+5)/6)*log(dt)
scalar ndf = 0.5*@ncoef*(@ncoef-1)
if @chisq(khi,ndf) < 0.05 then scalar test2 = 0
else scalar test2 = 1
```

```
endif
```

Annexe 2: Based model selection with all possible regression in Eviews

```
!a = 1
FOR !I =1 TO 7
equation eq!a.ls Y C X!i
!a = !a + 1
next
'Equation à deux variables'
FOR !I = 1 TO 6
FOR !J = !I+1 TO 7
equation eq!a.ls Y C X!I X!J 'equation à deux variables
!a = !a + 1
next
next

'Equation à trois variables'
for !i=1 to 5
for !j=!i+1 to 6
for !k=!j+1 to 7
equation eq!a.ls y c x!i x!j x!k
!a=!a+1
next
next
next

'Equation à quatre variables'
for !i=1 to 4
for !j=!i+1 to 5
for !k=!j+1 to 6
for !l=!k+1 to 7
equation eq!a.ls y c x!i x!j x!k x!l
!a=!a+1
next
next
next
next

'Equation à cinq variables'
for !i=1 to 3
for !j=!i+1 to 4
for !k=!j+1 to 5
for !l=!k+1 to 6
for !m=!l+1 to 7
equation eq!a.ls y c x!i x!j x!k x!l x!m
!a=!a+1
next
next
next
next
next
'Equation à six variables'
for !i=1 to 2
for !j=!i+1 to 3
for !k=!j+1 to 4
for !l=!k+1 to 5
for !m=!l+1 to 6
for !n=!m+1 to 7
equation eq!a.ls y c x!i x!j x!k x!l x!m x!n
!a=!a+1
next
next
next
```

```
next
next
next

'Equation à sept variables'
for !i=1 to 1
for !j=!i+1 to 2
for !k=!j+1 to 3
for !l=!k+1 to 4
for !m=!l+1 to 5
for !n=!m+1 to 6
for !o=!n+1 to 7
equation eq!a.ls y c x!i x!j x!k x!l x!m x!n x!o
!a=!a+1
next
next
next
next
next
next
next

'Selection du meilleur modèle'
Scalar BEST = 0
FOR !I = 1 TO 127
scalar IND = 0
scalar NV = eq!I.@ncoef
for !J = 2 TO NV
scalar te =@abs( eq!I.C(!J)/sqr(eq!I.@covariance(!J,!J)))
scalar ddl = eq!I.@regobs-eq!I.@ncoef
IF @tdist(te,ddl)> 0.05 then ind = 1
endif
NEXT !J
IF IND = 0 then
 IF eq!I.@R2 > BEST then scalar neq= !I
 BEST = eq!I.@R2

ENDIF
ENDIF
NEXT
```

References

Abdullah, O.B.-F.; Seraj, Y.A.; Sajjad, M.J. 2000. The determinants of domestic air travel demand in the kingdom of saudi arabia, *Journal of Air Transportation World Wide*, (2): 72-86.

Alperovich, G.; Machnes, Y. 1994. The Role of Wealth in the Demand for International Air Travel, *Journal of Transport Economics and Policy*, 28(2): 163-173.

Callaghan, N.; Tol, S.J. 2013. UK Tourists, the Great Recession and Irish Tourism Policy, *The Economic and Social Review*, 44(1): 103-116.

De Vany, A. 1974. The Revealed Value of Time in Air Travel, *The Review of Economics and Statistics*, 56(1): 77-82.

De Vany, A. 1975. The Effect of Price and Entry Regulation on Airline Output, Capacity and Efficiency, *Bell Journal of Economics*, 6(1): 327-345.

Haitovsky, Y.; Salomon, I.;Silman, L.A. 1987. The Economic Impact of Charter Flights on Tourism to Israel : An Econometric Approach, *Journal of transport economics and policy*, 21(2): 111-134.

Ippolito, R.A. 1981. Estimating Airline Demand with Quality of Service Variables, *Journal of Transport Economics and Policy*, XX1(2): 7-15.

Johnston, & DiNardo. (1997). Econometric Methods, Mcgraw-Hill, New York, U.S.A.

Jung, J. M.; Fujii, E.T. 1976. The Price Elasticity of Demand for Air Travel: Some New Evidence, *Journal of Transport Economics and Policy*, X(3): 257-262.

Lewis, B. R.; Mitchel, V.W. 1990. Defining and Measuring the Quality of Customer Service, *Marketing Intelligence & Planning*, 8(6): 11-17.

Schafer, A.; David, G.V. 2000. The future mobility of the world population, *Transportation Research Part A*, 34(3): 171-205.

World Bank 2014. IBRD-IDA. (s.d.). Consulté le 08 21. Available from Internet: <http://data.worldbank.org/data-catalog/world-development-indicators>.

AIRPLANE CABIN FOR ALL

Petra Matzenberger[1], Helmut Lemmerer[2], Bernhard Rüger[3]
[1,3] *Vienna University of Technology, Institute of Transportation, Research Centre of Railway Engineering, Traffic Economics and Ropeways, Vienna, Austria*
[2] *Vienna University of Technology, Institute of Transportation, Research Center of Transport Planning and Traffic Engineering, Vienna, Austria*

Abstract: Today's aircraft cabins often did not comply with the needs of people with reduced mobility. Due to several regulations it was expected that, just like railways already had, arrangements in air traffic would be set to improve accessibility for these people in aircraft cabins. The aim of our project Cabin4All was to implement and evaluate steps that provided an added value for disabled persons. These steps should also be efficient enough for airlines. With the help of a large survey at the airport in Salzburg it was possible to get a good overview of which problems different kinds of people had. Moreover, several networking workshops were held to bring together representatives from aircraft industry, railway industry and potential passengers and define the specific requirements.

Keywords: air traffic, cabin, accessibility.

1. Introduction

Due to the fact that there are already valid laws and additional national and international laws and EU-regulations against discrimination currently being prepared it is expected that, just like railways already have, there will be stricter requirements for accessibility in European air traffic in a few years. Currently there are several aides for people with reduced mobility in air traffic but during the flight only some needs are being met yet. Flight industry is increasingly caught between necessary equipment for peoples with special needs and the economic pressure to use all available space in an air cabin to maximize seats.

The aim of the project Cabin4All is to set up a clearly defined requirement catalogue as a key foundation for future aircraft development based on technological and ecological feasibility under consideration of what people with reduced mobility need. Many requirements have already been implemented in railways, so it´s easy to use the specific know-how for flight industry as well. The Cabin4All project is an exploratory study that primarily presents the cross-linkage between flight industry, railway industry and disabled persons. Under consideration of valid regulations and safety requirements the project should show which steps are viable and which steps should not be pursued.

2. General requirements of persons with reduced mobility

The study "European Standardisation of Accessible Tourism Services" found out that there are some lacks in EU legislation on accessibility. Moreover, most standards focus on technical specifications and few on service and quality management. Access Standards show considerable variation by European countries in the functional requirements they prescribe and in the dimensional and design requirements. (European Network for Accessible Tourism, 2009)

The right contact and the right manner with people with reduced mobility is one of their requirements. For this reason it is important to control the quality of the service management. Moreover it should be included in the user's requirements. Concerning the EU legislation 1170/2006 travellers with reduced mobility have the right to aides without any charge and without showing any medical reports. A report must only have to be shown if there are any risks concerning the health and security of the traveller, of other travellers or the boarding crew. (European Commission, 2012)

2.1. Situation concerning the airplane

Many different problems in a report concerning the air-travelling situation of persons with reduced mobility were mentioned by the European Commission:

"Disabled people and people with reduced mobility continue to come across many problems when travelling by air: a lack or unequal level of quality of service in Europe; too often unjustified refusals or restrictions of reservations or boarding based on unclear safety reasons; inconsistencies in the treatment of passengers who need medical oxygen onboard; limited level of awareness of passengers regarding their rights; limited percentage (around 40%) of pre-notification of their needs before travelling; lack of harmonisation of the interpretation of the regulation by national enforcement bodies; and lack of effectiveness in the treatment of complaints." (European Commission, 2011)

To obtain similar options as other travellers, certain assistance and facility elements have to be offered for persons with reduced mobility. It is illegal that this support cost anything due to non-discrimination rules. The service components which have to be achieved are located in the airport manager's authority on the one hand, and on the other hand, they have to be guaranteed by the cabin crew. The cabin crew is responsible for safety regulations and also for comfort. Safety regulations are, for example, on-board-emergency-equipment like seat belts, oxygen masks and life jackets. The

[1] Corresponding author: petra.matzenberger@tuwien.ac.at

catering with snacks and drinks belong to the comfort. Generally, the cabin crew is responsible for the safety of all passengers. But they do not have to support anyone with the food intake or with any medical issues. If someone needs support in general or help for the transfer from the seat to the toilette for example, the cabin crew has to help. In principle, the airline company or travel agency has the right to refuse the reservation or the journey if the safety regulations cannot be observed. If the person with reduced mobility gets the permission to travel, he/she usually has to inform the airline company at least 48 hours before travelling. The assistance at the airport is regulated in the EU guideline 1107/2006 and has to be free of charge.
According to the practical field, it would be better for people with reduced mobility to inform the airline at least one week before their travel date because the airport also needs some time for preparation and even handling wheelchairs can vary at all airports. (Mobilista, 2015).
Therefore the airports and the airline companies have categories, so called Special Service Request Codes (SSR). With the help of these codes it is possible to differentiate between different assistance needs and aid utilities. Most of the time, the categories are consistent across different airports and airline companies but vary in detail and amount. (Porter Airlines, 2016).
As an example the categories or codes of the Vienna Airport are mentioned as follows (Vienna International Airport, 2015; Vienna International Airport, 2016):

- WCHR (wheelchair – ramp): Passenger is able to walk long distances and climb stairs. He/she can move unaided in the cabin and negotiate aircraft steps. Help is required to/from air craft,
- WCHS (wheelchair – steps): Passenger cannot negotiate aircraft steps but can move unaided in the cabin,
- WCHC (wheelchair – cabin seat): Passenger is completely immobile and must be accompanied to/from his/her cabin seat,
- DEAF (deaf – passenger): Passenger with hearing or hearing/sight impediment,
- BLND (blind – passenger): Passenger with sight impediment,
- BLND/DEAF (blind and deaf passenger): Blind and deaf passenger, who can move only with the help of an accompanying person,
- DPNA (disabled passenger needing assistance): Disabled Passenger with intellectual or development disability needing assistance.

2.2. Situation concerning the train

The equality-law of disabled persons has had to be executed since 2016 concerning the situation of people with reduced mobility in the train. New railway carriages will only be bought with the equipment and design according to the standard of the relevant legislation. Old, non-barrier-free railway carriages which modification would not be economically reasonable will gradually be taken out of service.
Concerning accessibility current elements of the railway carriages are:

- Entrance: lifting devices, low floor wagons, boarding ramp, wide doors, call buttons for assistance during entry and exit,
- Parking positions for the wheelchair including plug sockets to charge the battery of electro wheelchairs.
- Folding tables,
- Identification markings in high contrast of handles and grips, package storage, stairs and door handles,
- Toilet: suitable for wheelchairs, tactile elements, emergency buttons, helplines and automatic sliding door,
- Information systems for the passengers: acoustic irradiation (voice mails or train staff), visual announcement (“2-senses- principle” – shown in figure 1),

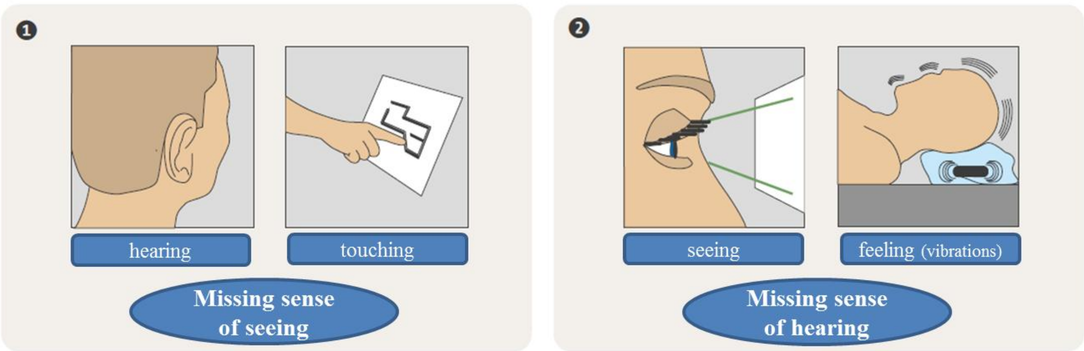


Fig. 1.
2-senses- principle
Source: Kalamidas (2006)

- Tactile elements: guidance system to the toilet, SOS-technology, guidance system to the exits, elevated buttons for entrance and exit doors, identification marking in high contrast for important infrastructure, sensor-controlled internal doors, tactile pictograms. (ÖBB-Holding, 2015)

Concerning the applicability of these elements in airplane cabins it must be said that it is not possible to transfer all of these elements because the stress capability of facilities in airplane cabins are different. For example, it is unfeasible to use the own wheelchair as a seat during the flight. Another obstacle for the use of one's own wheelchair is the width of 50 cm of the aisle in the airplane.

3. Method

One main part of the project Cabin4All was a survey at the waiting area of the airport in Salzburg and an online questionnaire. 1790 people were questioned at the airport Salzburg and 507 online. With the help of the survey at the airport it was possible to get an opinion of the average travellers with and also without reduced mobility and about their evaluation of accessibility in the airplane cabin. The link of the online questionnaire was especially sent to organizations and associations of persons with reduced mobility. For that reason a higher number of these persons took part online. The questionnaire included questions of different parts of the airplane cabin which the questioned people had to evaluate concerning satisfaction and problems. The entrance and exit of the airplane, the corridor of the cabin, the toilets, the seat, the storage of the cabin luggage and the airplane cabin in general were evaluated. The data analysis was done with the program SPSS 22. Figures and graphs were made by the program Microsoft Excel.

4. Results

4.1. General data

From the 1790 questioned people at the airport Salzburg, 58% were male and 42% female. Most of them were between 30 and 59 years. 83% of the questioned persons indicated that they had normal weight. The body height of the questioned people could be seen in figure 2.

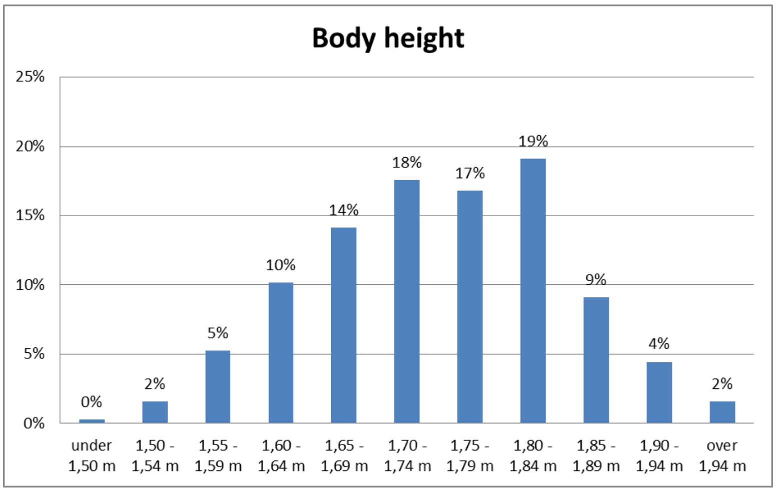


Fig. 2.
Body height of the questioned person at the airport Salzburg

16,5% of the questioned people answered that they had one or more disability. In comparison to the Austrian average, where according to the Federal Ministry of Social Affairs 20,5% of the population have a disability, it is visible that there are less handicapped persons at the airport (Leitner & Baldaszti, 2008). The 20,5% doesn't include pregnant people and people with little childen! Moreover, this percentage refers to private households. Persons in institutions are not included. As a result the number of highly disabled people is underestimated. (Bednar et al, 2008)

4.2. Requirements and problems of persons with a wheelchair

Figure 3 shows a dissatisfaction ranking of the different parts of the airplane cabin. Summing up this ranking, it is obvious that the toilet is the biggest problem of persons with a wheelchair. These results are from the online questionnaire.

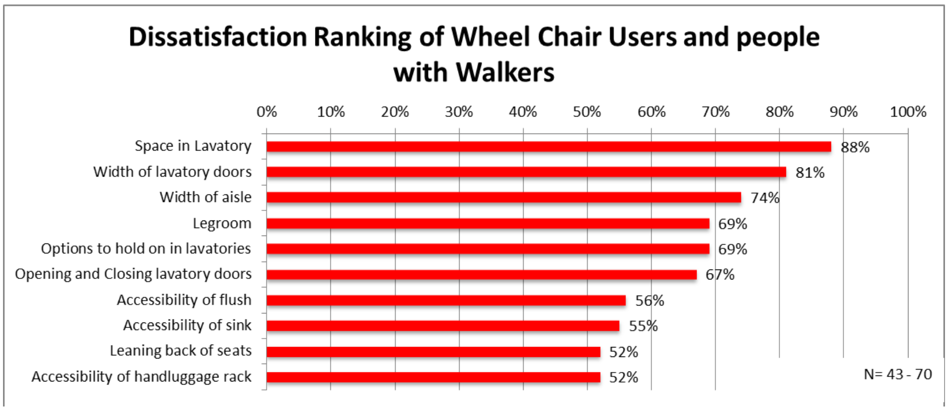


Fig. 3.
Dissatisfaction ranking of persons with a wheelchair or a walking frame

Concerning the problems of wheelchair users in the airplane cabin they answered that they especially had problems at their seats. For example, 67% of the questioned persons said that they had problems with clapping back the seat and 46% said that they had problems with the legroom. But the amount of participants was low (n=8-13) concerning the questions about the problems.

4.3. Requirements and problems of persons with visual handicaps

Most of the persons with visual handicaps said that they were unsatisfied with the seat. They also said that they had most of their problems with the seat. One eye-catching point is that visual handicapped persons had problems with the information through announcements (18%). This kind of information is probably very important for people with visual handicaps. That could be the reason why it should work very well for them. Acoustic irradiation is one element where the airplane could use the guidelines of the railway.
In Figure 4 and 5 it is possible to see the dissatisfaction rankings and the most frequent problems of persons with visual handicaps.

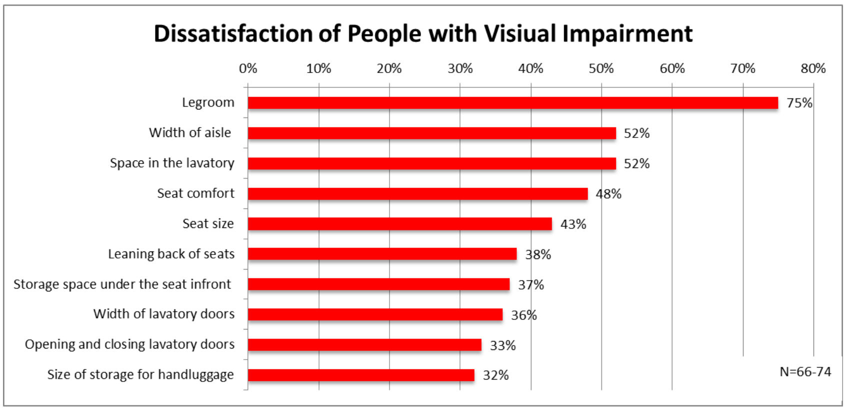


Fig. 4.
Dissatisfaction ranking of persons with visual handicaps

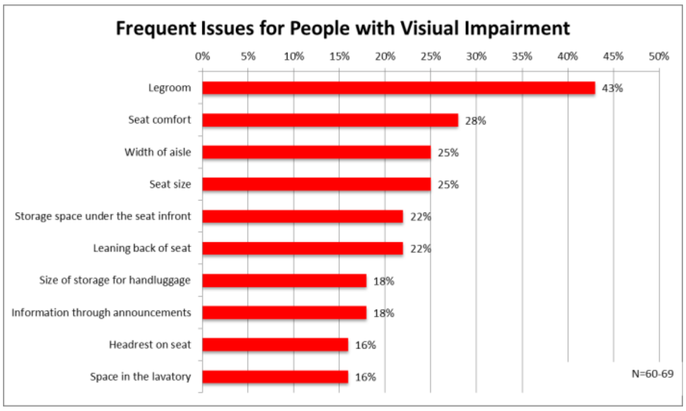


Fig. 5.
The most frequent problems of persons with visual handicaps

4.4. Requirements and problems of persons with little children

Persons with little children on their hands or with a pram are also persons who are hindered. That is why this group was questioned as well. In principle this group showed a higher dissatisfaction in comparison to other groups. The most dissatisfying element was the seat. Especially the legroom (79% were not satisfied), the comfort of the seat (63% were not satisfied), and the size of the seat (53% were not satisfied) were dissatisfying. Moreover, the aisle width was not satisfying for 63% of the questioned persons with little children. More results are showed in figure 6 and 7.
Concerning the situation in the train there are less problems with the legroom or the aisle width. There are guidelines suggesting that there should be a children area in each train. Moreover, there should be enough space at the entrance to turn around a pram or a wheelchair. Concerning recommendations the entrant area should be at least 150 x 150 cm (BMVIT, 2009). This is not feasible in the plane because there they have space issues.

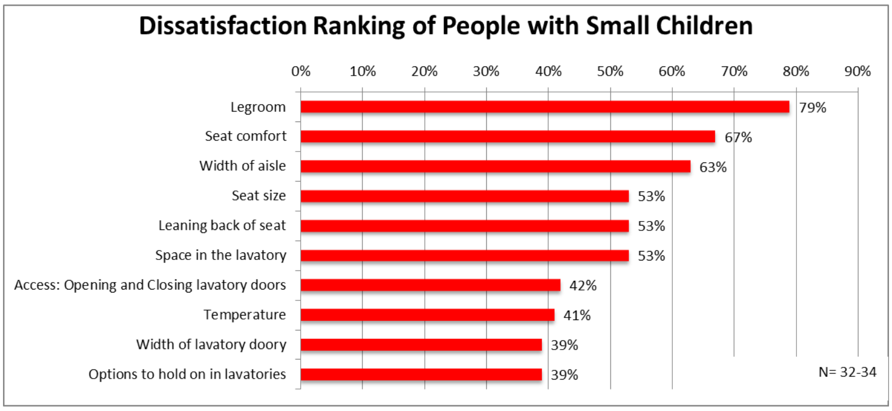


Fig. 6.
Dissatisfaction ranking of persons with little children

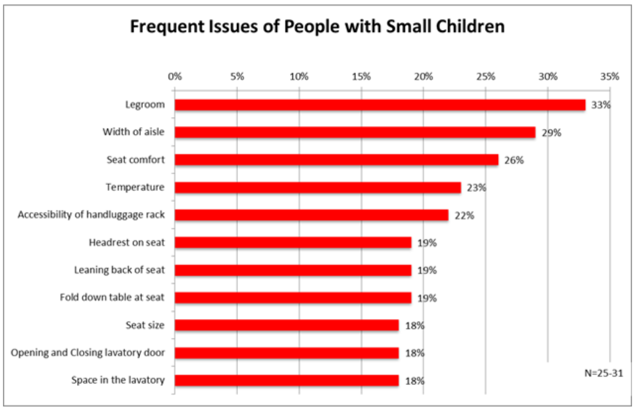


Fig. 7.
The most frequent problems of persons with little children

4.5. Requirements and problems of special groups (age, gender, body height and body weight)

Body weight
All in all, overweight people were less satisfied with the cabin than people with normal weight or underweight. They had the most dissatisfaction with the legroom. 70% answered that they were not satisfied with the legroom. Other dissatisfying elements were the space in lavatories (55%), the seat comfort (51%) and the seat size (49%). It was obvious that these dissatisfying elements were increasing with body weight. Overweight people had more problems with the seat than people with normal weight or underweight. 37% of the questioned persons with overweight answered that they had problems with the legroom. 22% of them had problems with the seat comfort.
Concerning underweight people, it is eye-catching that they were more satisfied in general than people with normal weight and overweight. One dissatisfying element of underweight people is the temperature in the cabin, where 31% were unsatisfied. Moreover, the temperature was also the biggest problem of underweight people. 29% had problems with it. Another eye-catching point is that underweight people had problems with the handle and grip options. For example, 18% of these people answered that they had problems with the handle options in the toilet.
Body height
In summary, tall people had more problems and a higher dissatisfaction than small people. The biggest problem of tall people was the legroom. 66% of persons who were over 1,89 metre tall had already had problems with the legroom. Actually, 87% of them were unsatisfied with the legroom. By the way, the seat comfort was also decreasing with the body height. Tall people were also unsatisfied with arm rests (49%) and neck-rests (48%) of the seat. Interestingly, Tall

people (over 1,89 metre) (32%) as well as small people (under 1,60 metre) (22%)were less satisfied with the accessibility of the sink than persons with average body height. Other dissatisfying elements of tall people were the seat size (57%) and the space in the lavatory (52%).

Small people (under 1,60 metre) had a bigger dissatisfaction with the accessibility of the hand luggage rack than tall and average-size people. 38% of them were unsatisfied with the accessibility of the hand luggage. Actually, 32% of the small people had already had problems with the accessibility of the hand luggage. Interestingly, small people (31%) were also more unsatisfied with the size of the storage of the hand luggage than the others. Moreover, the neck-rests of the seats showed a higher dissatisfaction with small people (30%). One more dissatisfying element of small people is the temperature. 31% of them were unsatisfied with this element and 18% of them had already had problems with this.

Age

Concerning people of the age of 70 years and older, it is eye-catching that they had in general a higher satisfaction but more problems than younger ones. Biggest problem and dissatisfying element of the elderly is the legroom. The group of the 70-year-old-ones and older-ones also had problems with the information through announcements. This is the only element where the elderly showed a higher dissatisfaction than the younger age groups.

Gender

Concerning the difference between men and women, it is obvious that men were much more unsatisfied with the seat than women. Maybe the reason is that they are taller than women. Most dissatisfying element of men was the legroom (71%). Concerning women it was the same, but only 65% of the women were unsatisfied with it. With the legroom men and women also had the most problems and also in this case men (32%) had more problems than women (24%). Typical women’s problems were the temperature (19% of all women had had problems with it) and the accessibility of the hand luggage rack (16% of all women had had problems with it). Also the dissatisfaction of these elements was higher with women (temperature 34% and accessibility of the hand luggage rack 22%) than with men.

4.6. Short-term and long-term service components

All in all, there are a lot of areas in the airplane cabin which could be modified concerning accessibility. A lot of short-term and long-term service components have to be changed to obtain a barrier-free airplane cabin. Some ideas for short-term and medium-term improvements are shown in Table 1.

Table 1
Ranked ideas for short-term and medium-term improvements

Ranking	Idea
1.	Mobile application - assistance
2.	Guidance system for visually impaired
3.	Accompanying person
4.	Staff training
5.	Bi-sensory information
6.	Special cutlery, tableware, tray
7.	Communication supporting items (symbol or card set for showing)
8.	High-contrast elements (especially in the toilet)
9.	Pre-information about special needs
10.	Triangle handle

5. Conclusion

Altogether, there are similar problems and requirements within the different groups of disabled persons according to the survey. Afterwards there are the top five problem areas which were mentioned by the questioned people:

- Legroom,
- Comfort of the seat,
- Space at the toilet,
- Aisle width
- Clapping back the seat.

The problems legroom and comfort of the seat were definitely the leading areas. In the project Cabin4All the comfort of the seat has a less important part because it is more a comfort criteria than a real problem. The legroom at the seat could be a real problem of certain people, for example of wheelchair users, tall persons or persons with an injury of the legs. Unfortunately, this result is unlike the actual trend of the flight business because at the moment the space between the seats is getting smaller and smaller. For example, the Austrian Airlines has reduced the space between seats at the end of 2015. Concerning the clapping back of the seat the reduced or changed space are probably the main problems. Especially for blind people or people with visual handicaps and wheelchair users the reduced or changed space could become a real hindrance.

The topic toilet in the airplane and especially the space at the toilet is the main problem of wheelchair users. Also the head of the stewardesses of the Austrian Airlines mentioned this problem in an interview. Most of the time wheelchair users are not able to use the toilet without the help of others. Especially due to less space and this makes it impossible for some of the wheelchair users to even use the toilet. From the stewardess's view the transfer of the wheelchair user to the toilet is another important problem. Often the disabled persons have no auxiliary persons with them. In the worst case, the cabin crew has to ask another passenger to help them with the transfer.

Travellers who have problems with the sensory organs are, on the one hand, persons with visual problems and, on the other hand, also persons with hearing impaired. One of the main problems for this group is to get information. This is the reason why announcements should be given in a 2-senses- principle . This is also one of the guideline points of the train.

In addition, there are some other guideline points for the railway system which could be implemented in the airplane system. For example, the train staffs are getting taught about handling disabled persons (ÖBB-Holding, 2015).

This should also happen with the cabin crew. In addition, the guideline for a barrier-free train says that 10% of the seats in a passenger train should be marked for persons with reduced mobility. The seats should be near the entrance and should be standardized across all cabins. (BMVIT, 2009) These are some guideline points which are also implementable in the airplane.

All in all, there are a lot of areas in the airplane cabin which could be modified concerning accessibility. Concerning this survey the best ideas for short-term and medium-term improvements were a mobile application-assistance and a guidance system for visually impaired.

Acknowledgements

The authors acknowledge the Federal Ministry for Transport, Innovation and Technology and the Austrian Research Promotion Agency for funding and supporting this project.

References

Bednar, M.; Floh, S.; Gabriel, C.; Luschin, P.; Miller-Fahringer, K.; Reinalter, A.; Rubisch, M. 2008. *Behindertenbericht 2008. Bericht der Bundesregierung über die Lage von Menschen mit Behinderungen in Österreich 2008*, Federal Ministry of Labour, Social Affairs and Consumer Protection, Vienna, Austria.

BMVIT 2009. Bundesministerium für Verkehr, Innovation und Technologie, Amt der Oberösterreichischen Landesregierung - Abteilung Gesamtverkehrsplanung und öffentlicher Verkehr, Amt der Steiermärkischen Landesregierung - FA 18A Gesamtverkehr und Projektierung, *Anforderungen an barrierefreie Eisenbahnfahrzeuge*.

European Commission 2011. Passenger rights – Main findings and next steps. Memo/11/232. Available from internet: <http://europa.eu/rapid/press-release_MEMO-11-232_en.htm>.[online: 24.07.2015].

European Commission 2012. Memo/12/422. Available from internet: <http://europa.eu/rapid/press-release_MEMO-12-422_en.htm?locale=en>.

European Network for Accessible Tourism, 2009. European Standardisation of Accessible Tourism Services. Available from internet: <http://www.accessibletourism.org/resources/soret-ambrose-valladolid-2010_final.pdf>.

Kalamidas, O.; Koch-Schmuckerschlag, C. 2006. *Barrierefreies Bauen für ALLE Menschen. Planungsgrundlagen*. Stadtbaudirektion Graz, Austria.

Leitner, B.; Baldaszti, E. 2008. *Menschen mit Beeinträhctigungen. Ergebnisse der Mikrozensus-Zusatzfragen 4. Quartal 2007*. Federal Ministry of Labour, Social Affairs and Consumer Protection, Statistics Austria.

Mobilista 2015. Alltag mit Rollstuhl. Fliegen mit Rollstuhl oder anderen Behinderungen. Available from internet: <http://mobilista.eu/54/fliegen-mit-rollstuhl-oder-anderen-beinhderungen> [online: 23.07.2015].

Netwiss, TU Vienna, Rodlauer Consutling GmbH, FH Joanneum Graz GmbH 2016. Results of the project Cabin4All. Available from internet: <http://www.netwiss.at/2207910/Cabin4All>.

ÖBB-Holding, 2015. *Evaluation Etappenplan 2015 und Ausblick*.

Porter Airlines 2016. Special Service Requests. Available from internet: <https://www.flyporter.com/Travel/Special-Service-Requests?culture=en-US> [online: 27.01.2016]

Vienna International Airport, 2015. Hilfestellung für „Passagiere mit eingeschränkter Mobilität. Qualitäts-Standards. Available from internet: <http://www.viennaairport.com/jart/prj3/va/uploads/data-uploads/Passagier/Quality_Standards_PRM_de.pdf> [online: 15.07.2015]

Vienna International Airport, 2016. Accessible Travel. Available from internet: <http://www.viennaairport.com/en/passengers/airport/disabled-accessible_travel> [online: 16.08.2016]

PASSIVE RADAR SYSTEM FOR SLOVAKIA

Nikolas Žáčik[1], Andrej Novák[2]

[1,2] The University of Žilina in Žilina, TheFaculty of Operation and Economics of Transport and Communications, Žilina, Slovakia

Abstract: The main problem in general aviation is still the rapid rising level of congestion in the airspace all over the world. It may cause a problem with the plane accommodating, controlling and plane tracking in the airspace with actually non-upgraded land facilities. This topic is a conclusion of 5 years long research about performances of radar technology in general. The main idea of this topic is to give solution to increasing tracking capacity in the airspace for very long time, substantially lower price in the short period of time with sufficient precision for safety increase. For this task we found out that one of the best technologies is the passive surveillance technology, previously used just for military operations but nowadays still more consulted in the civil sector. This article presents the findings from five years research in cooperation with company ERA. The second part of topic solved in the article is theoretical concept of building up the new radar network based on passive radar technology in Slovakia. Article shows the advantages and disadvantages of this passive radar architecture, in comparison with currently used primary and secondary radar network. The research is applicable as a theoretical base for all other countries, with some minor changes.

Keywords: radar technology, multilateration, passive radar, coverage, obstacle, tracking capacity.

1. Introduction

The main task of our project is to offer possible solution not only how to fulfill current needs and requirements of the air space, but also how to solve the problem with the rapid rising level of congestion of the airspace now and in the future. Our solution is based on a new type of technology which has come to civil aviation industry in the past few years: Passive Radar Technology (PSS). In our 5 years long research we were comparing all available and used radar technologies and systems to find one with the best option for future development of the air traffic control, navigation and surveillance. By upgrading the most of currently used surveillance systems there is no possibility to achieve sufficient performance for the future development of aviation industry. The upgrading of currently used radar systems could solve the situation for the short term. PSS technology is a long term solution to increase the capacity with a very high precision, during a very short time for very low costs (in comparison with active radar systems). Our conclusion is that one of the most suitable technologies for this task is the passive surveillance radar technology, previously used only for military operations as the strategic secret weapon but nowadays still more consulted in the sector of civil aviation. Our research is based on findings obtained in cooperation with a company ERA, which is the biggest distributor of passive radar technology and multilateration systems in the world. Other tasks summarized in the topic are to approximate operation and principle of the radiolocation facilities and to describe whole topic of PSS technology also from the historical point of view (development, invention, importance, current status). The article provides a brief overview of alternative solution of airspace coverage by passive radar technique in the territory of Slovak Republic (SR). The result based on the research is a clearly described geographical position of deployment of the PSS radar equipment in the geographical map of SR. This article leads you through information about advantages and disadvantages of using passive surveillance technology and multilatertion in Air traffic control network, as well as technical restrictions. Our conclusions are supported by ERA simulation programs for planning wide area mutilateration (WAM) networks and by consultancy experts. The outcome of this research is a short manual on how to proceed during planning PSS network in different areas and countries with different landscapes and which conditions need to be considered during planning.

2. Principle of work of PSS systems VS active RADARs

PSS system works without the transmitter. All active radars usually use the transmitter providing radars with ability of transmitting signal into the space. The signal in the space is reflected by the objects in the range of the radar only if objects have ability to reflect electromagnetic signal. Such ability is given by construction material of the object. The most of active radar technologies detects this reflected signal by antenna. If object is constructed of material which is not able to reflect electromagnetic signal or shape of the object is specially designed for deflection of this signal, the target will become invisible (undetectable). This is the main disadvantage of active technology which goes in a hand with acquisition and operating costs. PSS technology is able to bring convenient solution and solve these as well as many other problems.

For comparison, the main part of PSS is the system of several receivers. PSS system transmits any electromagnetic signal into the space. Its principle is based only on receiving electromagnetic energy from the space in radar range. Precise position of targets is determined by comparison with all detected signals from all receiving stations of PSS system. This kind of radar is the most common and the most frequently used in application to aviation in military sector. Nevertheless, this technology is still not completely used in civil air traffic. Potential of PSS technology is often

[1] Corresponding author:nikolas.zacik@fpedas.uniza.sk

underestimated by the civil air traffic sector. For air traffic control is nowadays the most common concept of active radar network based on impulse and primary radar technology.
PSS is working on principle of cooperative, independent tracking. PSS system consists of several side antennas located at different places and one central antenna which is used as reference point for all received signals at all antennas. After receiving of signals are all signals evaluated and compared by central antenna. Theoretically is PSS able to detect and track all possible sources of electromagnetic signals. In aviation is commonly used principle of transmitting and receiving message by using secondary radar technology used with cooperation with PSS. In case of this concept is assertion that PSS radar is transmitting any signal, false.
PSS does not transmit any signal, it only receives electromagnetic signals from the space by an antenna system. Despite of passive principle of receiving signals, PSS receiving antennas still need some source of this signal (echo) for tracking of the target. PSS radar is able to detect all kind of radio technical signal from the source. Radio technical signals are all electrical signals from all electronic devices. For this purpose can be sufficient for example transmitter of the radio, television, mobile network, avionic, radar signal or sight technology. The less common signals which is PSS able to detect are signals from household or foreign radars but also a jammer. All these kinds of signals are reflected from all objects in the sky and also on the ground. It creates natural signal which passive radar can process. For data of higher quality are compulsory more antennas in the system for process of evaluating data relative to reference antenna. From differences in the signal of separated antennas is possible to precisely determine position, direction and speed of target in the time.

3. Current situation of using multilateration equipment in SR

There is no multilateration system implemented in Slovak Republic nowadays. Also no PSS is used for civil operations and air traffic control in Slovakia. A few PSS are used for Slovak military air traffic control services. On the other hand, you can find three of these systems used by Air traffic control in Czech Republic. The exact name of this system of PSS radars is Wide Area Multilateration (WAM) system. In Czech Republic, this system is located in the area of cities Brno, Ostrava and Prague. Those three systems are able to cover the whole air space of Czech Republic and also the west part of Slovakia. In Czech Republic, there is also in use one Airport Multilateration (AMLAT) system as part of A-SMGCS in Prague. EUROCNONTROL is nowadays working on the surveillance services supporting the implementation of reduced traffic separation minima, by improving and harmonizing the surveillance infrastructure by using of MLAT systems, their implementation, evaluating, testing, prototyping and legislation for proper use. The main objective of SASS-C EUROCONTROL center for next year research (2017) is to find new tasks for which MLAT and MSPSR could be used, and how MLAT and PSR systems could influence tracking and surveillance in the aviation operations. Another task of the project is to find the best possible existing technology for purposes of MLAT and MSPSR systems to improve their efficiency in comparison with currently used systems for the same purpose.

3.1. Process of implementation of multilateration system for SR

Our research is based on assumption that Slovak and Czech Republic (CR) are very similar areas with similar ground segmentation (see Fig. 1 and 2 below). The most significant problem in CR was to build up WAM network in the area of mountains with sufficient coverage of air space because of the landscape shape which is the most limiting factor. The whole area of CR is 78 866 km² and more than 30% of Czech area is above 500 m above sea level. During WAM system planning in SR we have found the same limiting issue with the landscape. The area of SR is only 49 036 km², but the shape of the landscape is very mountainous (more than 35% of it). This is the main issue to be solved. After taking this into account, the methodology and experiences gathered during building up the Czech PSS system can be also used for building up the Slovak PSS system (mainly in problematical mountain parts) as well as many studies and expert´s opinions. The simulations of ERA company simulator, developed with the aim to design concepts of the architecture, the ERA company expert´s opinions and found historical data have shown that the ideal amount of central stations for the area of Slovak republic is number three. In this configuration and case of cooperation with Czech Air Traffic Control (ŘLP) there is a possibility to achieve in the air space of Slovakia, tracking information with higher precision or less number of used central stations in the network for lowering costs. In the air space of Slovakia in case of lowering costs acquisition during building up the new WAM system, there is an opportunity to reduce number of central stations to one. Disadvantage of the concept with one central station is lower tracking capacity of the system and slower data evaluation as well as congestion of only one central station. In concept of one central antenna all data will be preceded by one station, because this station will be a reference point for all other antennas in the terrain.

3.2. Limiting factors for designed architecture

The number of stations for coverage of Slovak air space dependent mainly on three limiting factors:

- The area which has to be covered
- Ground segmentations and mountains in the country
- The lowest flying level which has to be covered.

Those factors are crucial and restrictive in term of work principle of PSS radar technology. The principle is based on method of multilateraion. For this purpose it is necessary that PSS detects signals from targets direct visibility between the object and the radar. The condition of direct visibility between four antennas and the target in time must always be complied with. In the area of Slovak republic it is necessary to take into account the high mountains which in some areas exceed 2500 m above sea level. The most significant obstacles during planning are in this case are the Tatra Mountains. In case of request to cover lower flight level above ground level, it is necessary to use more central stations and side antennas.

3.3. Design of WAM system for area of SR

This concept of WAM system design for Slovakia is based on collected information about work principles of this system in cooperation with company ERA. They supported this project with materials which contain manual and basic information for design of WAM networks, the same as was used for building up the radar network in Czech Republic. Our concept for Slovakia has been designed for these cities:

Bratislava – we have chosen this area for better coverage in proximity of international Bratislava Airport in the capital of Slovakia from the lowest possible flight level. The main purpose is that there are expected aircraft operations in low altitudes, mainly during take offs and landings. This position will also ensure very precise coverage of whole Danubian Plain and sufficient coverage of western part of Slovakia. The western part of Slovakia situated behind Little Carpathians mountain is perfectly covered by Czech WAM network. In case of sharing the radar data between Czech and Slovak republic will be this part behind obstacle also under control of ATC. The condition of sharing this radar data is not required, as there won´t be flights in such a low altitude. WAM system designed for this area will partly cover the middle part of Slovakia. Our architecture concept for this area is to build eight stations in total. Five of them will be situated near the airport with direct visibility to lower altitude above area of Danubian Plain. Stations around the airport guarantee higher precision mainly in critical area of the airport. Other three antennas will be situated farther from the airport for coverage and better precision of system in other parts outside the airport.

Liptovský Mikuláš – this area was designed to improve the quality of coverage of whole WAM system mainly for mountain area, where the signal can be often shielded by obstacles for stations and antennas from Bratislava and Kosice systems. This central station has to ensure the coverage of northern Slovakia, mainly the area of High and Low Tatras. This system also provides coverage for the area of the third biggest international airport in Slovakia, airport Poprad – Tatry. Our architecture concept for this area is to build seven stations in total. Four of them will be situated near to the airport for the same reason as it is mentioned for WAM system Bratislava in article above. Other three antennas will be situated at the mountain comb of Low Tatras for better range and higher precision of system. The result will be better coverage of whole airspace above airspace of Slovakia, mainly in problematical mountain part. Designed concept will ensure coverage also in the area between hills, although, there is no expectation of any air traffic in such altitude just in case of emergency.

Košice – the main reason for choosing this location is the second biggest international Slovak airport **-** Kosice airport. Other reasons are similar as mentioned above for the area of Bratislava. This central station of WAM system will cover the whole eastern part of Slovakia. Our concept of architecture for this area is total of six stations. Three of them will be situated near to the airport for the same reason as it is mentioned for WAM system Bratislava in article above. Other three antennas will be situated at the mountain called Slovak Ore Mountains for better coverage and higher precision of system in the east part of Slovakia. The position of antennas at the elevated position will ensure direct visibility for whole east area. The result will be the better coverage of whole airspace above the airspace of Slovakia, mainly in problematical mountainous parts.

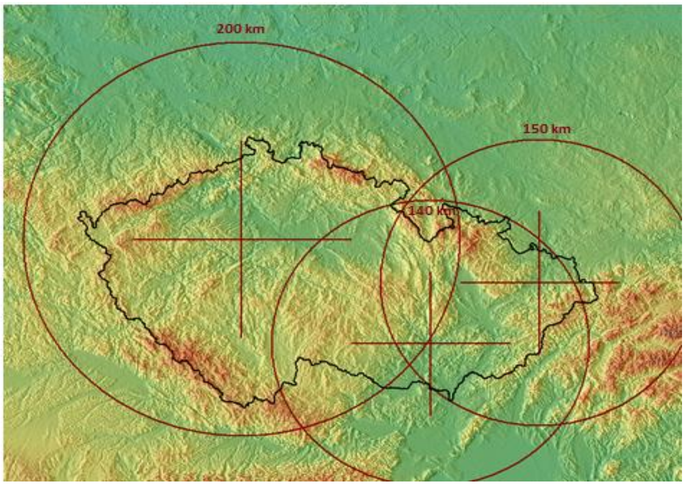


Fig. 1.
Ground segmentation in Czech republic and position of WAM central stations in CR area with partly coverage of SR. Source: ERA company

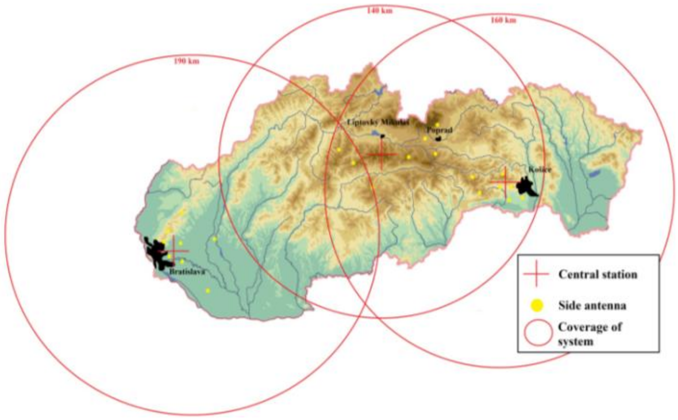


Fig. 2.
Design of WAM system for Slovak republic.
Source: Author Ing. Nikolas Žáčik

The best possible technology with the aim to build up new WAM network is actually the most modern Czech system: P3D-WS at all chosen positions of central stations. This technology removed bugs occurred in the previous versions and also meets all ICAO traffic safety requirements. Previous version P3D-40 was just beta testing version with lower maximal range. All radar centrals in this concept where chosen for the best possible coverage of whole required airspace of Slovak Republic. The concept of three centrals will not ensure the coverage of whole area of Slovakia from the ground, but will ensure the coverage around all international airports in the country as well as the coverage of airspace in the mountain from the altitude where the air traffic can be expected. All side antennas must be placed in the range of 100 km from the central stations. All antennas are communicating between each other and share information about the position of the target. Chosen architecture of WAM network and distance between separated antennas can ensure tracking targets in the range of 350 km in ideal terrain condition. Restrictive factor in maximal possible range is just range of the transponder station, which can effectively works just in range of 100 km. According to the recommendations of Era company, the minimal number is five antennas for one central station. The price of the whole WAM network designed for Slovakia, built up by company ERA is around 3 – 4 million euros. The whole research was supervised by ERA during regular consultations about each point of designing. The concept was developed from theoretical knowledge, based on simulations of ERA company simulator, developed following the design concepts of architecture in all terrain conditions. For better economical overview and advantages of this solution see graph at Fig. 3.

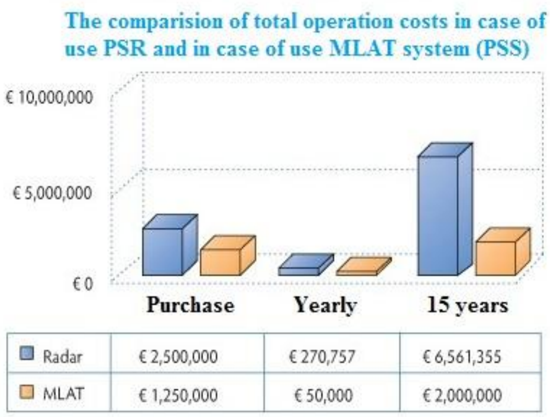


Fig. 3.
The comparison of whole operation costs, in case of using of primary radar (PSR), in comparison with MLAT system (PSS).
Source: (http://www.multilateration.com/benefits/cost.html)

4. Conclusion

The final conclusion of the project is to offer an alternative solution on how to build up a radar network and the radar coverage of the overall air space of Slovak Republic's territory. Our concept consists of PSS radar technology, which is provided by Czech company called ERA. This technology is characterized by high level of the precision, reliability and low operating expenses. During designing of WAM system in Slovakia, there were two possible solution concepts of positioning all stations and antennas. The first of them is to build up a network with three independent central stations with several antennas (in case of PSS technology: receivers) for each of them. For this concept is the most important the cooperation between all three stations and also between all antennas. The second possible solution is: to build up just one central station with more antennas in the space, as it is in the first case with 3 central stations, but the costs of this concept will be lower. The Disadvantage of this concept is a lower tracking capacity. After consultation and recommendations of specialists from company ERA, our recommended outcome of new WAM concept for Slovakia is the first solution: to build up a network with 3 separated central stations. The best location for this three stations regarding to terrain in the country are cities: Bratislava, LiptovkýMikuláš and Košice with total number of 21 antennas. The biggest challenge during designing the WAM network in Slovakia were the mountains, especially the area of High Tatras. PSS needs a direct visibility of detected target for correct and smooth operation. In our chosen concept we have achieved the coverage of entire airspace of Slovak Republic with the required range. In addition, the system covers part of the air space of surrounding countries. The range of one system of antennas with central station is approximately 350 km in dependence on ground segmentation. The price of the whole concept of designed WAM system is around 3 – 4 million euros. The exact price depends on the actual number of used antennas and stations. For better overview, one PSR applied for the same purpose, has the price of 3 million euros and its operating costs are 5 or 6 times higher than operating costs of PSS radar. The main advantage of WAM system is the increased level of safety in the air traffic.

Acknowledgements

This paper is published as one of the scientific outputs of the project: „Centre of Excellence for Air Transport ITMS 26220120065“.

References

Bugaj, M. 2011.The basic analysis of control systems on commercial aircraft, *Perner´s Contacts*, 6(5): 29-35.
ERA 2015.Web page. Available from internet: <http://era.aero/>.
Havel, K. et al. 2005. *Basic course for technical security personal of operation services*, LPS SR, Bratislava, Slovakia.
Jurasek M.; Kanak, J.; Okon, L.; Meri, L. 2014. Close Future of Slovak Weather Radar Network [online]. Slovakia, Bratislava: SHI. 2014. 2 p. Available from internet: <http://www.pa.op.dlr.de>.
Kazda, A.; Badanik, B.; Tomova, A.; Laplace, I.; Lenoir, N. 2013. Future airports development strategies, *Komunikacie*, 15(2): 19-24.
Laplace, I.; Kazda, A.; Tomova, A.; Badanik, B.; Lenoir, N.; Malavolti. 2009. E.FAST: Future airport strategies(2009). In *Proceedings of the* :*8th Innovative Research Workshop and Exhibition*,19-28.
Novák, A.; Pitor, J. 2011. Flight inspection of instrument landing system. In *Proceedings of the IEEE Forum on Integrated and Sustainable Transportation Systems, FISTS 2011*, 329-332.
Ochodnický J.; Matoušek, Z. 2013.Analysis of radio-location systems, Slovak Air Force Academmy of general , Slovakia.
OPERA 1999-2003. Final Report. Available from internet: <http://www.knmi.nl/opera/opera1/Final_Report.pdf>
Stevák, M. 2013. PORTABLE METEOROLOGICAL RADAR. Available from internet: <http://www.meteoradar.eu/onas.html>.
Svoboda, P. 2013. Perfect radar technique RAMONA, TAMARA, VERA can see steathbjects. Available from internet: <http://simon22.blog.pravda.sk/2013/09/10/skvele-pasivne-radary-ramonatamara-vera-vidia-neviditelne/>.
Turiak, M.; Novák-Sedláčková, A.; Novák, A. 2014. Portable electronic devices on board of airplanes and their safety impact, *Communications in Computer and Information Science*, 471: 29-37.
UJCOVÁ, M. 2013. *Commercial document: Wide Area Multilaterationinter materials*, Czech Republic.
Žáčik, N. 2013. *Comparison of tracking systems*. Bachelor thesis, University of Žilina, Žilina, Slovakia.
Žáčik, N. 2015. *Tracking systems*. Diplom thesis, University of Žilina, Žilina, Slovakia.

MODELING THE COSTS OF THE BIRD STRIKES PREVENTION

Aleksandra Nešić [1], Olja Čokorilo[2], Sanja Steiner[3]
[1,2] *University of Belgrade, Faculty for Transport and Traffic Engineering, Belgrade, Serbia*
[3] *University of Zagreb, Faculty of Transport and Traffic Sciences, Zagreb, Croatia*

Abstract: Range of diverse bird strike effects in air transport put spotlight on this subject in the air traffic industry. Every segment of commercial air transport is interested in this topic and could make a significant contribution because these kinds of events play major role in daily operations disruptions and having safety, economical and organizational influence. Because of its enormous importance in aviation questions are: Is it possible to avoid these events? At what cost? This paper tries to answer what are the costs of bird strike prevention. The first part of paper deals with prevention measures and systems; environment adjustments, trainings, contemporary and technological achievements for reducing bird strike risk. International Bird Strike Committee and ICAO statistical data will complete image of frequency and consequences of these events. Focus will be on comparing benefits of implementing new systems and theirs costs. Finally, based on expected air transport growth investment in control risks cold be comprehended as investment in air traffic safety and progressive cost management..

Keywords: air traffic safety, costs, bird strike prevention, measures.

1. Introduction

Bird strike as ever-present risk in the air traffic became very popular in the past decades and inspired numerous scientists to seek for better solutions to this problem. This challenging issue raises questions regarding air traffic safety, bird strike costs and preventive measures. Modern technical devices are very expensive and some of them won't have same effect on every bird spices therefore detailed analyses are needed before implementing preventive equipment. Bird strike effects on flight depend on various elements like birds mass, density, part of airplane that suffered the impact, airplane material, angel of the bird strike, flight phase, airplane category, engines type, bird spices and etc. Probability of bird strike, as second element of bird strike risk, is being difficult to evaluate and mainly depend on preventive measures that are being used and on biodiversity of certain location. Contemporary methods are used to estimate both severity and bird strike probability.

Bird strike presents common risk in aviation which very often causes incidents particularly in the vicinity of airports. There is, however a lack of systematic approach for real-time bird strike assessment. Some authors (Ning et al., 2013) develop models for the bird strike probability estimation whilst generally estimations are based on the creation of a probabilistic model, inferences about changes to the states of the accident shaping or causal factors can be drawn quantitatively (Ancel, et al., 2015) or on inductive reasoning approach which is employed to develop a prototype hybrid decision support tool whose main objective is to build probabilistic causal models representing the safety risk involved in aviation accidents (Oztekin and Luxhøj, 2010). Some authors (Kermanidis, et al., 2006) developed simulation techniques related to development of suitable material damage models and for simulating the complex failure modes and unfolding mechanisms of quasi-static penetration of simple 'tensor skin' strips, which are representative of the complete leading edge composite structure of the aircraft. Bird strike consequences measured by blade deformation and its modeling is also provided in many experimental tests (Mao et al., 2009 and Salehi et al., 2010).

Majority of authors treat bird strike problems as a part of safety related problems during the aircraft operations, take-offs and landings (Čokorilo et al., 2011; Čokorilo, 2011; Čokorilo et al., 2014), and there is a lack of research dedicated to the cost benefit safety issues (Čokorilo, 2008; Čokorilo et al., 2010; Čavka and Čokorilo, 2012).

Distinctiveness of bird strike costs is its complexity and difficult separation from other costs in air traffic industry. Bird strike could have multiple effects and costs of such event will be calculated as sum of costs of single effects. Beside repair costs, delay/cancelation costs take special place because of theirs possible effect on succeeding flights. No matter what the cause of flight delays are, they are very expensive for aviation industry. Per ITA average unit cost per minute of delay going from 39.4 Euros to 48.6 Euros for the airlines.

Damage and withdrawal costs are determined by extend of damage and MRO company which is servicing the airplane. Extend of damage will mostly depend on size of bird and number of birds that participated in collision. (EASA, 2009) stated that from 1999 to 2008 the majority of birds involved were flocks of large birds (45%) followed by strikes from single large birds (31%). Parts that are the most reported as damaged in bird strikes are the most exposed airplanes parts: engines, wings and windshield.

2. Contemporary bird strike preventive measures

Bird strike preventive measures could be divided into four groups: habitat management, bird movement monitor devices, devices for dispersing birds and chemical aids. These elements will be combined depending on local characteristic. What has to be acknowledged when it comes to bird strike preventive measures is that same measure will not have same effect on two different locations; also effect could be permanent or temporary.

[2] Corresponding author: oljav@sf.bg.ac.rs

2.1. Habitat management

Complex problem like bird strike requires collaboration between different subjects within air transport and outside of it. Three main factors would be airport, air traffic company and municipalities authorities. Multiple elements cooperation is necessary because certain areas will be more attractive to birds then others due to existence of elements that provides food and shelter to the birds. Risky areas will be airports:

- Grassy areas within and outside of airport surface woodland and agricultural fields,
- Near to lakes, seas and globally water rich areas,
- Freshly excavated lend,
- Closeness to sewage or landfill.

It is obvious that effective habitat management requires collaboration with multiple organizations and it is almost impossible for airport to manage this kind of situation on its own. Critical areas that are mention above require careful analysis through few phases. First phase would be detailed observation of airport environmental with accent on topographical, biological, geographical and urban characteristics. Analysis of collected data should be done through second phase which final result should be evaluation of how risky concrete airport area is. Biology experts should be part of the team that conducts this research for analyzing bird behavior patterns. Third phase would suggesting which measures would be most effective and feasible in concrete case in order to reduce bird strike risk. Fourth phase is implementation and evaluation phase. This process needs to be cycle process to ensure that safety standards are met.
Collaboration between different institutions is emphasized during the fourth phase of implementation. For example, analyze of certain airport area may suggest that drying out the field, or landfill relocation is necessary to remove birds from the critical territory. Airport vicinity could be municipality or private property which makes this problem even more complex out of legal and ownership reasons. Habitat management is ever present measure because even if great modifications are not necessary, maintenance of airport area is constant to keep flight zone safe.
This kind of approach to the problem gives the best results because of its long term and comprehensive nature. The most effective way is proactive approach which means infrastructural and urban planning with considering bird strike problem in air transport. In those way costs of landfill relocation, drawing up field and etc. would be avoided because original location would not be accepted as proper because of the problem that may cause. It is clear that with this air transport demand and traffic volume it is not possible to find perfect location every time and to predict bird problem in the future. Therefore, except organization measures others measures need to be applied known as habitat management.
Costs of organizational measures are probably the highest among the bird strike mitigation measures. This type of measures include long term planning, multiple organization collaboration and each organization will have its own costs on this project, complex and expensive terrain modifications which requires engaging trained stuff and proper equipment.

2.2. Bird movement monitor devices

Airport field is wide area and it is difficult to make sure if birds are present in the airport environment and to quantify them. The main purpose of bird radar is to detect small objects movements. Nowadays, different model of radars are being used for tracking birds and other animals. Some of them are multifunctional and beside birds monitoring, they have additional functions, like weather surveillance radar (WSR) that has been used to study bird movements and bat roosts since the late 1950s in the USA. In the early 1990s the WSR-88D (also known as NEXRAD, or NEXt Generation RADar) replaced the older WSR-57, WSR-74S, and WSR-74C radars in the national network (Gauthreaux and Schmidt, 2013). The company DeTect (USA, Florida) developed the ‘Merlin radar system’ specifically for detection and tracking of birds and bats (Figure 1). It is a dual radar system with an S-band HSR and an X-band VSR. The effective range of the VSR is 3 to 5 km and 5 to 7 km for the HSR. Merlin software processes, analyses and records the radar information (Brabant and Jacques, 2010).

Fig. 1.
Different Versions of Merlin Aircraft Birdstrike Avoidance Radars
Source: DeTeact site: <http://www.detect-inc.com/DeTect%20info%20-%20wind/Technical_Data_Sheet_-_MERLIN_Bird_Radars_%20Wind_models_1205.pdf>

Lately Accipiter Avian Radar became very popular for its efficancy and flexibility in use. It can detect and track birds in the vicinity of an airport to within one meter and 2.5 seconds of their actual position. Accipiter has developed an advanced dish that provides unmatched 3-D surveillance. For a multi-transceiver system, an antenna rotates horizontally while a second antenna spins vertically (Watson, 2009).
Is radar going to be used for tracking birds and which model will be chosen for this purpose depend on multiple elements like airport characteristics, level of bird strike risk and funds available. Table 1 shows some of radar model being used for this purpose with their main characteristics and average costs.

Table 1
Different Models of Contemporary Radar Being Used for Bird Tracking

Bird radar model	Range for detecting birds (max)	Characteristics	Price
High-resolution marine surveillance radar	14 km	X-band and S-band version	Not available
Accipiter Avian Radar	20 km	Mobile or fixed version	$200,000 to $1 million per airport
WSR-88D	120 km (75 miles)	Two operational modes	$5,000,000 each unit

2.3. Devices for dispersing birds

Devices for dispersing birds is group of devices that is used for temporary eliminating birds from the critical area, this devices in basic aren't lethal but in certain cases could become deadly. Devices for dispersing birds are guns, laser guns, speakers, repellers that emit ultrasonic waves, scarecrows, trained predators… Sound devices are often used for this purpose, numerous models are in use worldwide with different swapping frequencies and sound that mustn't been disturbing for people. Contemporary measures also include modern repellents which generate ultrasonic waves and with automatically varied frequency. Nowadays mostly solar powered ultrasonic repellents are being used in different areas, from agriculture to air transport. Ultrasonic Bird Repeller Detection belongs to this group of measures, producing an ultrasound of 118dB, on the average will cover a distance of 45.02 m^2 while the 23.98W with an ultrasound of 123dB will cover a distance of 232.26 m^2 when placed on the elevation of 0.78m but when placed on the elevation of 1.86m, their average area coverage will be 175.83 m^2 and 429.53 m^2 (Figure 2). About 5-6 pieces of the 23.98W de vice will be needed to cover a hectare sized field (Ezeonu et al., 2012).

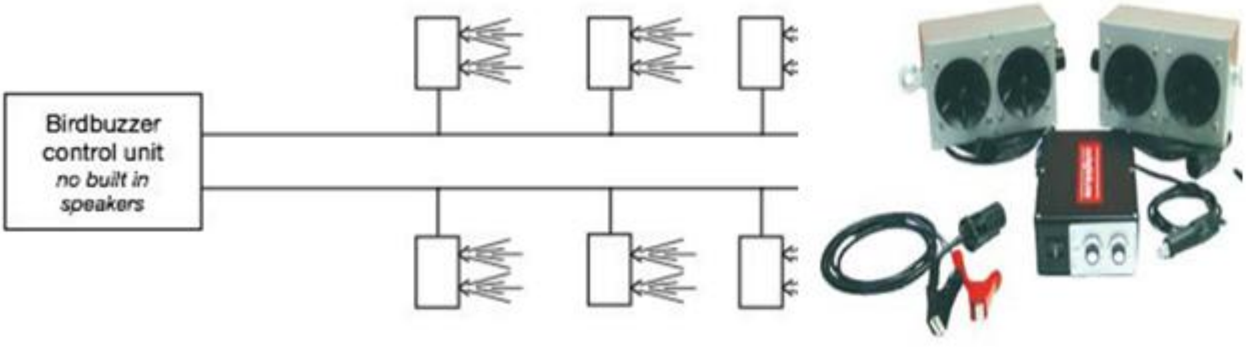


Fig. 2.
Scheme of the Ultrasonic Bird Repeller System and its Elements
Source: <http://www.copybook.com/airport/companies/scaringbirdscom/articles/birdbuzzer-ultrasonic-bird-repeller>

Bird Gard Super Pro Amp is another device used for bird problem mainly in agriculture and at airports which cover a larger territory, even up to 25 acres (Figure 3). It consists of 20 speakers that change the sound every 6 minutes. The device is able to broadcast sound in the range of 125 decibels. The power supply is a solar device is resistant to all weather conditions. Bird Gard Super Pro Amp is mainly used in Australia (Djordjevic, 2012).

Fig. 3.
Bird Gard Super Pro Amp Dispersing Device
Source:< http://www.birdcontrolpro.com/bird_gard_super_pro_amp.htm >

Beside audio, devices with visual effect are also used and their effect varies on bird spices. It has been found that the use of lights at night in high rise buildings can significantly increase the likelihood of nighttime migratory fatalities. Light apparently causes disorientation and attracts birds to structures resulting in impact and death.

Table 1
Different Models of Contemporary Bird Dispersing Devices

Model bird dispersing device	Range for detecting birds (max)	Characteristics	Price
QuadBlaster QB-4	6 500 sq. ft.	Bird repeller designed for indoor and semi-enclosed use	$556.75
Ultrason X	3 600 sq. ft.	Ultrasonic (silent-to-humans) bird repeller designed for outdoor use or in semi-enclosed areas	$670
BroadBand PRO	6 acres	Both sonic & ultrasonic bird repeller, option to include 3 visual scares.	$725
Super QuadBlaster QB-4	6 500 sq. ft.	Ultrasonic pest bird repeller + flashing strobe light is a multi-sensory attack	$670
Bird Gard Super pro Amp	25 acres (10 hectares)	Fully programmable, with adjustments for volume, specific sound combinations, daylight, night, or 24-hour operation.	3300 Euro

Source:< http://www.bird-x.com/ultrasonic-bird-control-pages-103.php> and <http://www.sperietori.ro/en/produs/95-bird-gard-super-pro-amp>

2.4. Chemical aids

Chemical aids include all chemical substances which purpose is eliminating birds or food for birds in the airport area. Chemicals are divided in two groups: lethal and non-lethal. Lethal method is very effective but also very controversial due to environmental changes and problem with endangered spices. Chemicals are the cheapest of all previously mentioned measures. Areas with endangered spices must be extra cautious because lethal measures are forbidden. The most common example of using this method is using chemicals to eliminate insects after digging land due to infrastructural changes on the airport. In that way bird will lose food source and inters in airport area.
Non-lethal measures are known as chemical repellents and would evoke two kinds of behavior: first is bird reflective withdrawal or escape due to taste, odor, and irritation; second group of non-lethal measures is causing psychological effect and illness. There is variation on behavior between different spices, for example this method has stronger effect on mammals then on birds, also different birds spices react differently to chemicals. The number of chemical bird repellents is limited, only two are registered for use in the United States: methyl anthranilate and anthraquinone. Methyl anthranilate is a primary repellent that produces an immediate unpleasant sensation that is reflexive and does not have to be learned. As such it is most effective for transient populations of birds Methyl anthranilate has been used with great success at rapidly dispersing. Anthraquinone is a secondary repellent that has a gastronomic effect that is not instantaneous (Clark and Avery, 2013).

3. Costs caused by bird strikes

Because of its complexity estimating of total costs caused by bird strikes in the air transport is very challenging. This kind of costs are far from the bird strike damage costs, that are often interpreted as bird strike costs. According to bird Strike committee USA bird and other wildlife strikes cause more than $650 million in damage to US civil and military aviation annually. In addition, bird strikes put the lives of crew members and passengers at risk — more than 200 people have been killed worldwide as a result of wildlife strikes since 1988 (Nicholson and Reed, 2011). In most cases bird strikes would cause negligible or minor damage to the airplane and flight will continue without disruptions. Sometimes pilots wouldn’t even notice that the bird strike has occurred and strike was discovered at regular airplane technical service.
For creating image of bird strike costs a few questions have to be answered like: How often bird strike happens? What is severity/damage of strike? What are effects on the flight?
<u>How often do bird strikes occur?</u>
Bird strikes are daily events but not all of them have the same effect or cause the same costs. In order to prevent this kind of events predicting them is the key of the problem. Per FAA There have been about 142,000 wildlife strikes with civil aircraft in USA between 1990 and 2013 (about 11,000 strikes at 650 airports in 2013). It needs to be acknowledged that probability of bird strike is not constant during whole flight. Take off/climb and decent/landing are the most endangered flight phases and the great majority of strikes happened during this phases, cursing flights level are too high and bird’s presence is extremely rare therefore bird strike during this phase is unlike to happen but it is not impossible. It is difficult to estimate exact number of strikes because not all of them are reported. Although bird strikes are daily events, accidents with major damage and human loses caused by these events are not that often. On the average, aircraft crashes every eighteen months as a result of a bird strike related incident (Thomas, 1990).
<u>What is severity/damage of strike?</u>
Level of damage caused by bird strike depends on multiple factors like mass of the bird, angle of the impact, matter density, material type and part that suffered the strike. It is clear that exposed parts are the most endangered. Per Boeing three-quarters of bird strikes involve the wing or engines. Engines on the most popular models of large jets, such as the Boeing 737 and the Airbus A320, are not certified to withstand an impact with birds larger than four pounds

(Dukiya and Gahlot, 2013). Repair actions would be taken based on damage degree, if bird strike was not detected during flight servicing will take place during regular technical checks. Engine, as the most vulnerable part of the airplane, beside enormous influence on the safety is giving one more problem - its repair is extremely expensive. Repair of one engine could cost up to few million dollars.

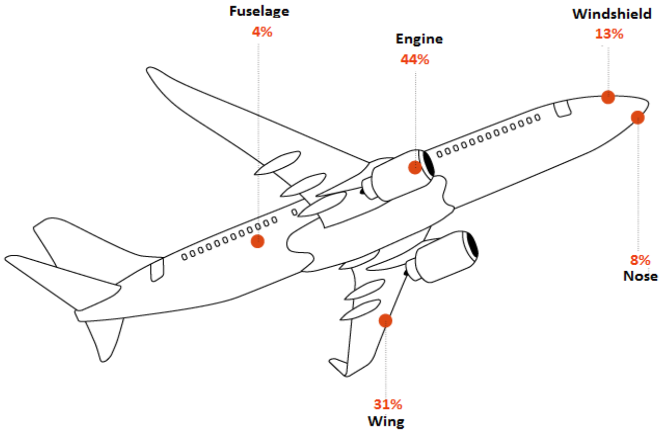


Fig. 4.
Locations of Bird-Strike Damage
Source:(Nicholson and Reed, 2011)

<u>What are effects on the flight?</u>
Bird strike effect on flight greatly depends on part of the airplane that suffered impact. Roughly based on part that suffered impact expected effects are: engine – loss of thrust; windshield – decompression or visibility decreasing; tail – decreasing of stability and maneuverability. As mentioned before not all of the bird strike will have influence on the flight, in most cases flight will be finished without any problems. Expect repair of the damage caused by bird strike and costs of repair material, airplane withdrawal from the traffic and maintenance staff working hours costs there also other bird strike related costs. Collision with bird might require immediate grounding which will lead to flight delay or cancellation and costs that follow this events, also company reputation will be questioned as well as passenger decision to chose same company again.

4. Preventing bird strikes model and costs

Developing model for preventing bird strikes at airports requires analysis of all bird spices that inhabit area and all other biodiversity and biological characteristics of certain area characteristics. Based on analysis airport must be classified into one of following categories:

- Areas with high risk – areas rich with water, insects, migration paths, farms;
- Areas with middle risk – ordinary areas without extra elements that attract birds;
- Areas with low risk – drought and desert areas.

In certain cases area could temporary become very attractive to birds and cases like that require immediate short term actions to remove elements that attract birds which means that presence of temporary activities on the airport must be included in the analysis. The most common case that requires temporary actions is land excavation which is leading to insect’s presence on the surface.
After airport classification, possible modifications should be considered. This modifications could be minor like installing safety nets but in some situations extensive transition actions are required with multiple subjects included. Large modifications are always very expensive and no matter if other measures are applied or not this activities are classified as large investments with high costs.
Except mentioned area adaptations other contemporary technical devices could be used individually or in combination with other devices. Which of this masseurs will be applied depends on first step and analyze of bio-characteristics and bird species features. Basically using dispersing, monitoring and chemical aids is considered as medium investment with medium or low costs but in certain cases modern equipment with multiple functions or combination of few measures could be very expensive and considered as large investment. After terrain modifications and/or technical equipment installation results of implementation must be monitored and evaluated. In case results are unsatisfactory process must be repeated.

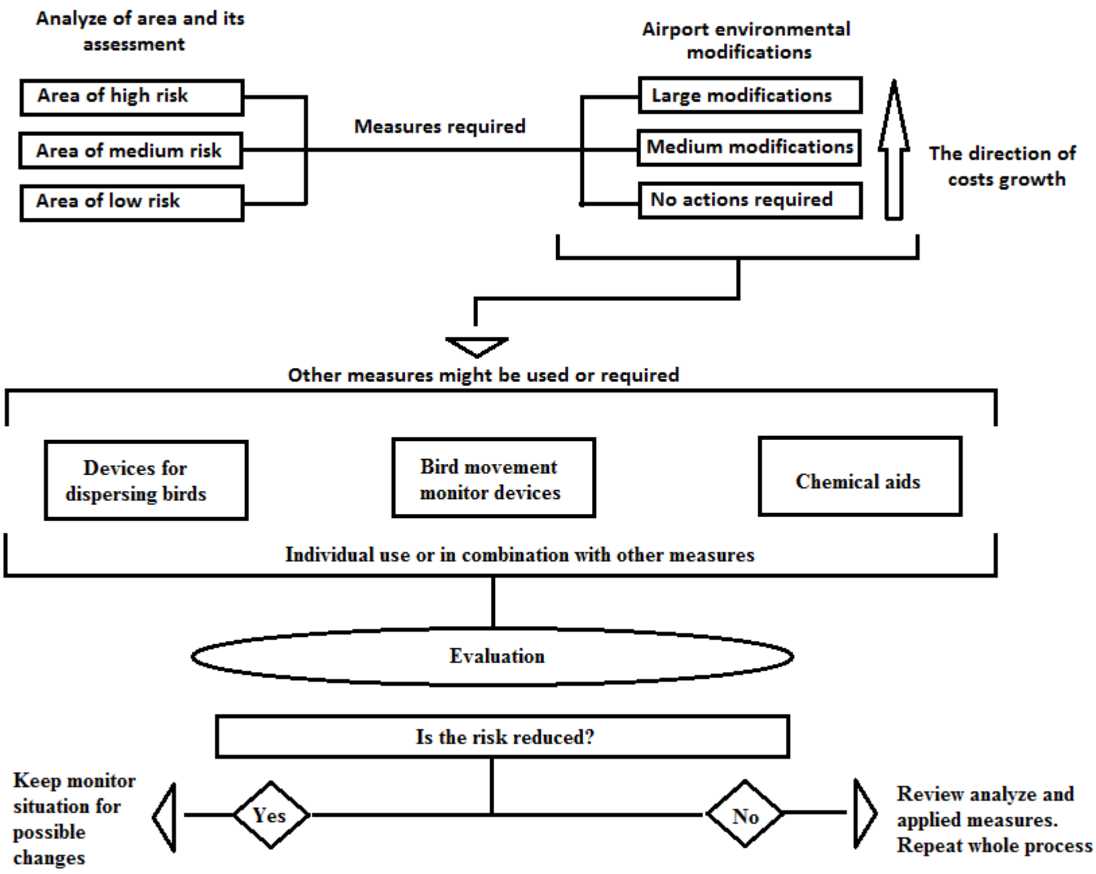


Fig. 5.
Process of Applying Measures for Mitigating Bird Strike Based on Analyze and Airport Assessment

5. Discussion and conclusion

Worldwide expansion both air traffic and birds population is requiring more effective and creative solutions for this problem. Fact that there is no universal solution complicates problem even more. Impact on air traffic safety and enormous costs caused by this problem just confirm that bird strike phenomenon must not be ignored. Complete elimination of this risk is ruled out as an option, this risk is ever present and it is possible only to mitigate it.

In conditions of difficult economy terms and high competition additional bird strike costs are undesirable and companies can't afford expensive repairs, delays, cancelations and airplane withdrawal. Except this costs, there is whole other group of costs which amount is almost impossible to estimate, that costs are costs of lost demand, passengers dissatisfaction, influence on company reputation and modal split. On the other hand managing bird strike risk could be very expensive and overcome airport available budget for this purpose and assistance of other organizations might be needed.

Bird strike management should not be considered as short term project, it is non-stop process. Even if airport is evaluated as bird strike safe area or applied measures gave desired results, that is not point where process ends; constant monitoring and regular reevaluations are required to make sure that there are no new circumstances and that airport maintains safe.

References

Ancel, E.; Shih, A. T.; Jones, S. M.; Reveley, M. S.; Luxhøj, J. T.; Evans, J. K. 2015. Predictive safety analytics: inferring aviation accident shaping factors and causation, *Journal of Risk Research*, 18(4): 428-451.

Birdbuzzer Ultrasonic Bird Repeller, scaring birds.com <http://www.copybook.com>.

Brabant, R.; Jacques, T. 2010. Chapter 9. Research strategy and equipment for studying flying birds in wind farms in the Belgian part of the North Sea. *Management Unit of the North Sea Mathematical Models (MUMM),* Gulledelle 100, Brussels, Belgium.

Center for severe weather research. Available from Internet: <http://www.cswr.org>

CAA. 2014. *Wildlife Hazard Management at Aerodromes - CAP 722*, Civil Aviation Authority, Aviation House, Gatwick Airport South, West Sussex, UK.

Clark, L.; Avery, M. 2013. *Chapter 3: Effectiveness of Chemical Repellents In Managing Birds at Airports*, USDA National Wildlife research center. University of Nebraska, Lincoln. 25-35 p.

Čavka, I.; Čokorilo, O. 2012. Cost - Benefit Assessment of Aircraft Safety, *International Journal for Traffic and Transport Engineering,* 2(4): 359 – 371.

Čokorilo, O. 2008. Risk Management Implementation in Aircraft Accident Cost Analysis. In *Proceedings of 12th Air Transport Research Society (ATRS) World Conference, Athens, Greece*.

Čokorilo, O. 2011. Quantified risk assessment modelling of aircraft landing operations, *Scientific Research and Essays,* 6(20): 4406-4413.

Čokorilo, O.; Gvozdenović, S.; Mirosavljević, P.; Babačev, N. 2010. The Impact of aircraft incident on the unit operating costs of civil aircraft. In *Proceedings of 12th World Conference on transport research (WCTRS), Lisbon, Portugal*.

Čokorilo, O.; Gvozdenović, S.; Vasov, Lj.; Mirosavljević, P. 2010. Costs of Unsafety in Aviation, *Technological and economic development of economy*, 16(2): 188-201.

Čokorilo, O.; Mirosavljević, P.; Gvozdenović, S. 2011. An approach to Safety Management System (SMS) implementation in aircraft operations, *African Journal of Business Management*, 5(5): 1942-1950.

Čokorilo, O.; De Luca, M.; Dell'Acqua, G. 2014. Aircraft safety analysis using clustering algorithms, *Journal of Risk Research*, 17(10): 1325-1340.

DeTeact Merlin Avian Radar system, Technical data sheet. Available from Internet: <http://www.detect-inc.com>.

DeVault, T.; Blackwell, B.; Belant, J. 2013. *Wildlife in airport environments: preventing animal-aircraft collisions through science-based management*, Johns Hopkins University Press, Baltimore, Maryland, U.S.A.

Djordjevic, A. 2012. *Analyze and bird strike prevention in the air transport*, Graduate thesis, Faculty of transport and traffic engineering, University of Belgrade, Belgrade, Serbia.

Dukiya, J.; Gahlot, V. 2013. An Evaluation of the Effect of Bird Strikes on Flight Safety Operations at International Airport, *International Journal for Traffic and Transport Engineering*, 3(1): 16-33.

EASA 2009. *Bird population trends and their impact on Aviation safety 1999-2008*, Cologne, Germany.

Ezeonu, S.; Amaefule, D.; Okonkwo, Godfrey. 2012. Construction and Testing of Ultrasonic Bird Repeller, *Journal of Natural Sciences Research*, 2(9): 8-17.

FAA Federal Aviation Administration. 2015. Available from Internet: <http://www.faa.gov/ >.

Gauthreaux, S. and Schmidt, P. 2013. *Wildlife in Airport Environments: Chapter 13 Radar Technology to Monitor Hazardous Birds at Airports*, USDA National Wildlife research center, University of Nebraska, Lincoln, U.S.A

Kermanidis, T.; Labeas, G.; Sunaric, M.; Johnson, A. F.; Holzapfel, M. 2006. Bird strike simulation on a novel composite leading edge design, *International Journal of Crashworthiness*, 11(3): 189-202.

Mao, R. H.; Meguid, S. A.; Ng, T. Y. 2009. Effects of incidence angle in bird strike on integrity of aero-engine fan blade, *International Journal of Crashworthiness*, 14(4): 295-308.

Nicholson, R.; Reed, W. 2011. Strategies for prevention bird strike events, *AEROMAGAZINE*, 17-24.

Ning, H.; Wang, J.; Chen, W. 2013. Lévy flight-based real-time bird strike risk assessment for airports, *Journal of Risk Research*, 16(5): 513-521.

Nohara, T.; Weber, P.; Premji, B.; Krasnor, C.; Gauthreaux, S.; Brand, M.; Key, G. 2005. Affordable Avian Radar Surveillance Systems for Natural Resource Management and BASH Applications. In Proceedings of *Radar Conference, IEEE International*.

Oztekin, A. E.; Luxhøj, J. T. 2010. An inductive reasoning approach for building system safety risk models of aviation accidents, *Journal of Risk Research*, 13(4): 479-499.

Salehi, H.; Ziaei-Rad, S.; Vaziri-Zanjani, M. A. 2010. Bird impact effects on different types of aircraft bubble windows using numerical and experimental methods, *International Journal of Crashworthiness*, 15(1): 93-106.

Thomas, S. 1990. *Bird Hazard Management at Manchester Airport*, Manchester Airport Plc Report, Manchester, UK.

Watson, B. 2009. Striking Back with Avian Radar, *Wings Canada's national aviation magazine.*

MISMANAGED GO-AROUNDS AND THE NEED TO MITIGATE THEIR OCCURRENCE

Mark Manchanda[1], Ivan Sikora[2]
[1] *Jet Airways Mumbai, India*
[2] *School of Mathematics, Computer Science and Engineering, Tait Building – C110, Northampton Square, London, UK*

Abstract: A missed approach (otherwise known as a go-around) is a part of an instrument approach procedure. It is a maneuver conducted by crew when an instrument approach procedure cannot be completed to a landing.
Main objectives of the study:

- To measure the performance of flight crew performing unexpected go-arounds and the number of errors made. (In a simulated environment)

Sub-objectives of the study:

- To determine whether a co-relation exists between the occurrence of error and the number of missed approaches carried out.
- To evaluate the severity of the errors.

A standardized grading system was used to measure the errors observed, the grading system was adapted from the grading system adopted by the airline industry currently. Constraints were imposed on the crew (weather) to observe the effects of external stress factors on crew performance. 15 sets of crew were tested from Feb 14 to July14 on 3 types of aircraft, B-777, B-787 and A-320 (full flight six axis simulators).

Keywords: go-arounds, mis-managed go-arounds, undesired aircraft state during a missed approach, performance errors.

1. Introduction

A missed approach (otherwise known as a go-around) is a part of an instrument approach procedure, it is a manoeuvre conducted by a pilot, when an instrument approach cannot be completed to a landing. This could be due to a variety of reasons, but the most likely reasons for a missed approach are, ATC (Air Traffic Control) or the meteorological conditions existing at the time of the approach. Flight crew errors are considered to be the primary factor in seventy percent of approach and landing incidents/ accidents. Studies have shown that the errors tend to be of a cognitive nature, among others they tend to be errors of judgment and errors caused due to a loss of situational awareness.

Due to the fact that go-arounds are an uncommon manoeuvre for most pilots, the hypothesis was that errors would increase with every missed approach or go-around that is carried out. A study was conducted to observe the performance of flight crew performing unexpected go-arounds, and determine whether a correlation exists between the occurrence of errors, and the number of missed approaches the crew carried out.

2. Study

A Scenario in a simulated environment was created to allow the pilots to fly from point A to point B.
The fuel provided to the crew was sufficient to carry out a maximum of four approaches.
15 sets of crew (a total of 30 pilots) were used in the study; their age group ranged from 24 years to 60 years and their flying experience ranged from 700 hours to 18,000 hours. All the participants were male and type-rated and current on the aircraft they were being observed on.
All 15 sets of crew attempted two approaches and two go-arounds or missed approaches. 7 sets of crew attempted a third approach and a go-around before a diversion was considered.

2.1. Grading and evaluation of the crew's performance

The sessions were observed and graded according to a set of performance indicators and competencies. A competency is commonly defined as a combination of the knowledge, skills and attitude needed to perform a task according to a prescribed standard. A three-point scale (1= poor performance, 2=acceptable performance, 3=ideal performance) was used for the study.
The data collected was classified according to the following performance markers:

1. (Technical) Automation
2. Procedures
3. Knowledge
4. Communication
5. Decision-making
6. Situation awareness
7. Workload management (Non-technical).

[1] Corresponding author: markmanchanda@gmail.com

While the evaluation of the Technical markers (Automation, Procedures and Knowledge) is relatively straightforward, the non-technical markers present more of a challenge. In order to remove any bias and subjectivity on the part of the observer, the grading criteria is based on the NOTECHS system created by the European Air and Space Agency (EASA, formerly known as JAA), and further explained by Flin 2003, pp. 95 – 117):

"Five operational principles were established to ensure that each crewmember receives as fair and as objective an assessment as possible with the NOTECHS system.

1. Only observable behaviour is to be assessed - The evaluation must exclude reference to a crewmember's personality or emotional attitude and should be based only on observable behaviour. Behavioural markers were designed to support an objective judgement.

2. Need for technical consequence - For a pilot's non-technical skills to be rated as unacceptable, flight safety must be actually (or potentially) compromised. This requires a related objective technical consequence."

2.2. Analysis of simulator observations

The observations can be looked at in two ways, the occurrence of errors per crew, and the number of actual errors.

Occurrence of errors: while some crew made a few errors on the 1st attempt - 3 out of 15 made errors (20%) the other 12 were error free, the errors increased as the crew undertook more approaches. The errors increased to 8 sets of crew out of 15 on the 2nd approach (53%), and on the 3rd attempt every single set of crew that attempted an approach made an error 7 sets of crew out of 7 (100%). It is important to note here that two crews who were totally error-free **did not** attempt the third approach.

Number of errors: for the number of errors the author looked at the data set as a whole to gauge the total number of errors possible. Given that there were 15 sets of crew and they were graded according to 7 markers, this allowed for a possibility of a total 105 errors. On the 1st attempt by all the crew a total of 4 errors were observed out of a total of 105 possible errors (3.8%), on the 2nd attempt a total of 16 errors were observed out of a total of 105 possible errors (15.23%). On the 3rd attempt however only 7 sets of crew attempted approaches and subsequent missed approaches so the maximum amounts of possible errors were 49, out of which a total of 15 errors were observed (30.6%)

Occurrence of error rating 1 (most severe error)

The author then looked at where errors occurred. It was found that which each approach as the stress of making a landing increased, the crew was committing more errors, with the majority being in decision making and situation awareness. For example, attempting to accomplish a landing with the tailwind component greater than 15kts, or actually going below the decision height and making a landing. On the first approach no errors on decision-making were observed.

The following charts were created from the data collected.

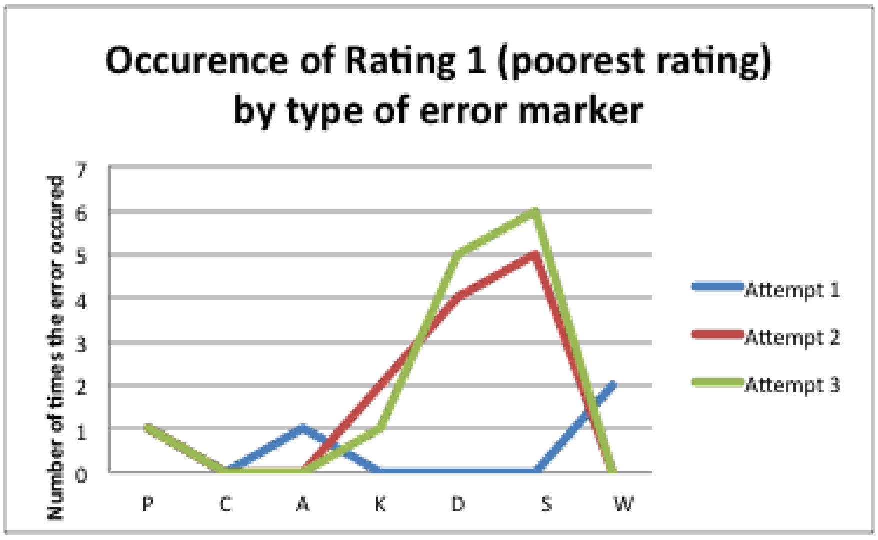


Fig. 1.
Occurrence of rating 1 (poorest rating) by type of error marker

This can be seen more clearly when we look at the charts for Rating 1 (Fig. 2) and Rating 3 (Fig. 3) separately:

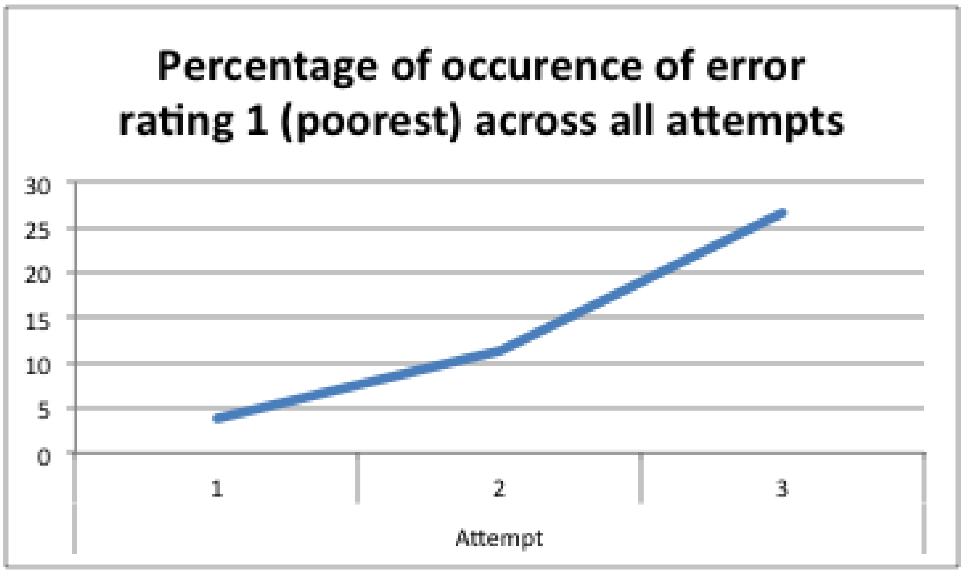


Fig. 2.
Percentage of occurrence of error rating 1 (poorest) across all attempts

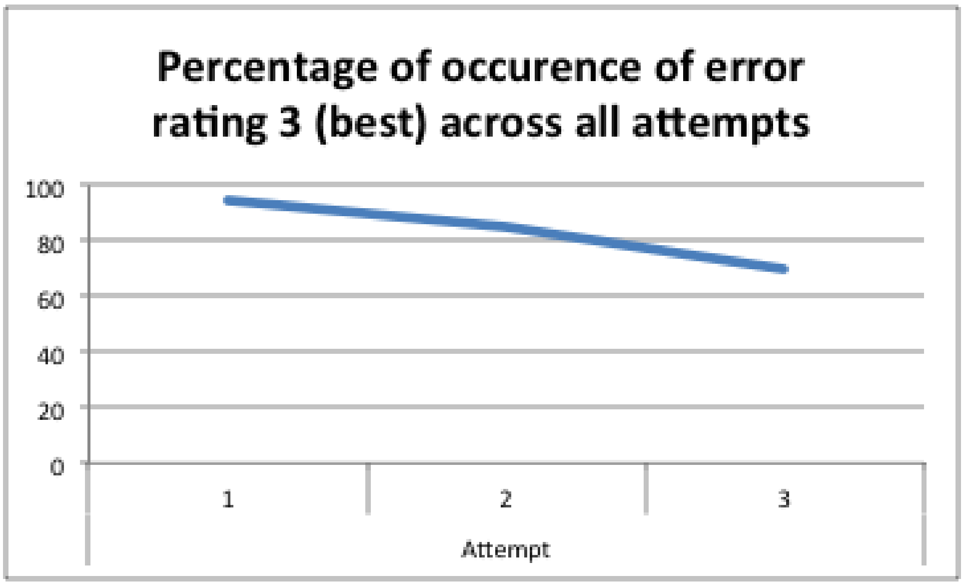


Fig. 3.
Percentage of occurrence of error rating 3 (best) across all attempts

3. Implications of mismanaged go-arounds in the aviation industry

This incident above shows the threat that mismanaged go-arounds can pose to flight safety. A degradation of situational awareness on the part of the crew almost led to an undesired aircraft state. As the research conducted demonstrates the errors increased with each subsequent go-around. As noted in the result section not only did the incident of errors increase on each subsequent go-arounds but the number of errors also showed a steep increase. Given the published statistic (Weigmann and Shappell 2003) that 70 to 80% of all aviation accidents are caused by human error it is therefore of vital importance to identify where these errors occur and take steps to reduce the possibility of their occurrence.
The hypothesis of this study was that human errors would increase with every missed approach or go-around that is carried out. This study clearly shows that mismanaged go-arounds are a potential source of error.

Objective	**Outcome**
To measure the performance of flight crew performing unexpected go-arounds and the number of errors made	It was noted that errors did occur when flight crews had to perform a go around. These increased with each subsequent attempt. On the first attempt 20% of the flight crews made errors in at least one performance marker. This increased to 53% on the second attempt and 100%

	(in at least one performance marker) on the third attempt.
To determine whether a correlation exists between the occurrence of errors and the number of missed approaches the crew carries out	There was a noted degradation in performance with each unexpected go-around. In addition to the occurrence of errors increasing, the number of these errors also increased. On the 1st attempt by all the crew a total of 4 errors were observed out of a total of 105 possible errors(3.8%), on the 2nd attempt a total of 16 errors were observed out of a total of 105 possible errors (15.23%). On the 3rd attempt however only 7 sets of crew attempted approaches and subsequent missed approaches so the maximum amounts of possible errors were 49, out of which a total of 15 errors were observed (30.6%).

4. Conclusion

Failing to abandon a risky approach when necessary can be disastrous, but several times in recent years go-arounds, formerly considered a simple maneuver, have themselves ended in disaster. Go-arounds occur between one and three times every 1000 flights (Flight International 29th July 2014). This gives rise to a very interesting question: is it safer to continue and land off an unstabilized approach or carry out a go-around? According to the Flight Safety Foundation 3.5-4% of all approaches are deemed to be unstable[2].

The results show strong and unambiguous support for the hypothesis, allowing the author to conclude that even though the research was single blinded if a more elaborate double-blinded process could be undertaken, the results would be similar. The results clearly show that a deficiency lies in the cognitive element of human information processing and not with knowledge, procedures or any of the technical elements. Sadly the current training and recurrent training programme's in force at a majority of airlines worldwide do not give the airlines the flexibility to prioritize issues that arise from time to time. Dated regulatory requirements sadly dictate current training programme. Endorsement training and recurrent training syllabi concentrate on missed approaches with an engine failure but do not practice or recommend the practice of full power two engine missed approaches, which is where the mis-management arises. In fact the pilots surveyed during the BEA study felt they were more than adequately trained for single engine missed approaches but not for those when all engines are operating. To quote flight international " Go-arounds are frequently infrequent and although they are an unexceptional procedure, that does not mean for pilots they are an everyday occurrence"

Until such time as EBT or another alternate form of training allows airlines the flexibility to adjust their training syllabus, it is the strong recommendation of the author that airline seriously consider a limit on the amount of missed approaches that a flight crew can accomplish and only attempt a 2nd or 3rd approach if the weather improves substantially.

References

Airbus Industrie. 2014. *Flight Operations Briefing Notes: Human Performance Error Management.* Available from Internet: <http://www.skybrary.aero/bookshelf/books/194.pdf>.

BEA, (2013). Study on Airplane State awareness during Go-around. Available from Internet: <http://www.bea.aero/etudes/asaga/asaga.study.pdf >.

Beaty, D. 1995. *The Naked Pilot: Human Factors in Aircraft Accidents,* Marlborough: The Crowood Press.

Brain, A. 1997. *Beyond Human Error in incident investigation: why people make mistakes*. Queensland Mining Industry Health and Safety conference proceedings.

Busse, D.K. 2002. *Cognitive Error Analysis in Accident and Incident Investigation in Safety-Critical Domains,* PhD Thesis, University of Glasgow.

Dekker, S.W.A. 2002. *The Re-invention of Human Error, Technical Report*, Lund University of Aviation.

Embrey. D. *Understanding Human Behavior and Error*, Human Reliability. Available from Internet: <http://www.humanreliability.com/articles/UnderstandingHumanBehaviour andError.pdf >.

FAA. 2008. *Aeronautical Decision Making* (FAA-P-8710-69). Available from Internet: <http://faasafety.gov/gslac/ALC/libview_normal.aspx?id=56413>.

Flin, R. et al. 2003. Development of the NOTECHS (Non-Technical Skills) System for Assessing Pilots' CRM Skills, *Human Factors and Aerospace Safety*, 3(2).

Harris, D. 2011. *Human Performance on the Flight Deck,* Surrey: Ashgate Hollnagel, E., (1983), *Why Human Error is a Meaningless Concept*. Position Paper for NATO Conference on Human Error, Bellagio, Italy 1983.

[2] A stabilized approach is one where the aircraft is on the desired approach path and glideslope, at the correct speed and in the landing configuration. All the parameters must be fulfilled before reaching a pre-determined point normally 1000ft.

Kepczynski, A. 1997. *The Human Factor in Aviation Accidents*, SkyNet Research. Available from Internet: <http://www.d-n-a.net/users/dnetGOjg/Hfactors.htm>.
Peters, G.A.; Peters, B.J. 2006. *Human Error: Causes and Control*, Boca Raton: CRC Press.
Pooley, E. 2013. *The Study of Accidents and Serious Incidents Involving a Go- around*. FSF Go Around Safety Forum. Available from: <www.skybrary.com>.
Qatar Airways Flight Training Department. 2014. Operations Manual Part D General, QTR-FO-026 (rev 05A).
Rasmussen, J. 1978. Notes on Human Error and Prediction, *Riso-M*, no. 2139, Riso Library, Roskilde, Denmark.
Reason, J. 1990. *Human Error*, Cambridge: Cambridge University Press.
Reason, J. 2013. *A Life in Error*, Surrey: Ashgate.

INFLUENCE OF PERFORMANCE DEGRADATION ON AIRCRAFT SAFETY

Đorđe Pantović[1], Olja Čokorilo[2]
[1,2] University of Belgrade, Faculty for Transport and Traffic Engineering, Vojvode Stepe 305, 11000 Belgrade, Serbia

Abstract: The aim of this paper is to determine the influence of aircraft performance degradation on necessary take-off field length. In this paper, the methodology of determination of required field length for aircraft take-off is presented. In order to determine the influence of aircraft performance degradation on required take-off field length, it is necessary to calculate the approximated values of aircraft lift and drag coefficients. After calculating aircraft lift and drag coefficient values, an equation of required lift-off field length is implemented. In order to solve the above mentioned equation, it is necessary to make some assumptions of constant values in equation such as air density, runway friction, aircraft mass and the runway length required to lift-off. These values can be measured in exploitation of an aircraft in real conditions and recalculate the runway length required. During model evaluation, authors concluded that required field length for lift-off and take-off is increasing with aircraft drag increase which has a great influence on air traffic safety, especially in a situation where aircraft experiences engine failure during takeoff. In order to maintain high level of air traffic safety, authors proposed several actions that need to be implemented in aircraft exploitation process. The influence of the aircraft performance degradation on required take-off field length has never been analyzed before, although there is a possibility to implement this particular methodology in the aviation industry in a practical manner.

Keywords: aircraft, safety, performance, drag, performance degradation.

1. Introduction

In aviation, the most critical phases of flight in terms of aircraft safety are considered to be take - off and landing phases (Čavka et al., 2014; Čokorilo et al., 2010; Čokorilo et al., 2011; Čokorilo et al., 2014). Safety reports from The European Aviation Safety Agency (EASA) indicate that about 44% of aircraft accidents occur during runway operations, ground operations, approach and initial climb and as a consequence of controlled flight into terrain (EASA, 2015). For this reason, it is necessary to pay special attention during the process of analysing and calculating aircraft performance parameters in these critical phases of flight. This issue is of particular interest because, in practice, the degradation of the performance characteristics of an aircraft during exploitation process is often neglected and overlooked. During research process, authors have found that previous researches on this particular topic were primary focused on performance degradation of aircraft and its elements related to aircraft reliability and effectiveness and not as an issue related to aircraft exploitation quality or aircraft safety during flight. The aim of this paper is to analyse the influence of aircraft performance degradation of aircraft safety during take-off operations. Given the fact that the degradation of aircraft performance mainly reflects in an increase in aircraft drag, it is necessary to perform a detail analysis of influence of aircraft drag increase on required take-off field length and the influence of aircraft drag increase on characteristic values of flight parameters at this flight phase such as v_1 decision speed, aircraft pitch rotation speed v_r, and the take-off safety speed v_2 (Cavcar et al., 2004). It is particularly interesting to analyse the issues related to the required accelerate and stop distance. It is necessary to perform a detailed analysis of aircraft performance in the event of one engine failure during take-off and initial climb (Ford, 1998).
In the second chapter of this paper, the mathematical model of aircraft performance degradation influence on required take-off field length is presented. In the first and second section of this chapter, methodology of gathering data of interest is presented. By usage of airliners intern documents such as Flight Crew Operating Manual (FCOM), authors calculated necessary data for proper model formulation. Aircraft performance data necessary for the formulation of the mathematical model of aircraft drag increase influence on required take-off field length were gathered from FCOM published by national flag carrier Air Serbia, for aircraft Airbus A319/320 which operates in Air Serbia fleet (Air Serbia, 2011). By usage of aircraft performance take-off charts (RTOW), authors determined the mathematical function of required take-off field length increase with the increase of aircraft drag. In this particular case, the model has been made for the case of take-off from Paris Orly airport from runway 08. In order to make required take-off runway length estimations for certain airport it is necessary to use the data from valid RTOW chart of airport for which the estimation is made.
In the third section of the second chapter, the model results are presented and discussed. During model evaluation, the authors noticed several potential hazardous situations which can occur as a consequence of aircraft drag increase which are also discussed in this chapter. At end of this chapter, authors proposed several actions that need to be implemented in order to decrease the negative influence of aircraft performance degradation on aircraft safety. In the final chapter of this paper, concluding remarks are presented.

2. The model

The method of estimating the influence of aircraft performance degradation on required take-off field length is presented for an aircraft Airbus A319-100, but can be determined for every other aircraft. In order to define the model

[2] Corresponding author: oljav@sf.bg.ac.rs

with top precision possible, it is necessary to define the gathering process of input data. The aircraft take-off performance data is published by aircraft manufacturer in FCOM in take-off section. The first step in model formulation is the estimation of aircraft lift and drag coefficients. In this case, the lift and drag coefficients are estimated for entire aircraft and not for its components separately.

2.1. Aircraft lift coefficient calculation

Aircraft lift coefficient calculation is a complex problem because the forces acting on aircraft are variable which leads to a conclusion that lift equation should be a differential equation. However, in this particular case, problem can be solved without usage of differential equations. Since aircraft lift coefficient describes aircraft aerodynamic characteristics and its position in airflow, it is possible to determine a moment of time during aircraft take-off process when it is possible to calculate aircraft lift coefficient value. The problem can be solved by usage of this methodology because the lift coefficient values are of no interest during aircraft ground roll. The first equation which can be used for aircraft lift coefficient calculation is the basic equation for calculation of lift coefficient of an aircraft with constant speed and height in certain flight level, as it is shown in (eq.1),

$$mg = \frac{1}{2}\rho v^2 S C_l \tag{1}$$

Where m is aircraft mass, g is Earth's gravity, ρ is outside air density, v is aircraft velocity, S is effective wing surface and C_l is lift coefficient. Equation (1) obviously cannot be used in this form for several reasons. First reason is that aircraft accelerates during take - off therefore speed is not a constant value. Second reason is that effective aircraft wing surface (S) and aircraft lift coefficient (C_l) are not same for different flaps and slats positions and third, the outside air density varies for different air temperature and pressure values. In order to calculate aircraft lift coefficient by using the equation (1) it is necessary to apply several corrections. Outside air density can be approximated with usage of outside air temperature (*OAT*) and pressure which both can be measured. Aircraft take-off parameters are published by aircraft manufacturer in RTOW charts for different values of *OAT* (Fig. 1.).

A320214 - JAA	IAE V2500-A1 engines	PARIS - ORLY ORY - LFPO	08	23.0.1 10-MAY-05 AE214B02 *V20
QNH 1013.25 HPA Air cond. On Anti-icing Off All reversers operating Dry check No reversers on dry runway		Elevation 277 FT TORA 3320 M Isa temp 14 C TODA 3320 M rwy slope 0.07% ASDA 3320 M	2 obstacles	DRY

OAT C	CONF 1+F			CONF 2			CONF 3		
	TAILWIND -10 KT	WIND 0 KT	HEADWIND 10 KT	TAILWIND -10 KT	WIND 0 KT	HEADWIND 10 KT	TAILWIND -10 KT	WIND 0 KT	HEADWIND 10 KT
-7	79.5 4/6 151/52/54	82.4 2/4 162/62/64	83.3 2/4 166/66/67	79.8 4/6 149/49/54	82.4 2/4 159/59/63	83.2 2/4 162/62/67	80.1 4/6 151/51/54	82.4 4/4 162/62/64	83.1 2/4 164/64/66
3	78.8 4/6 149/52/54	81.9 4/6 161/61/63	82.8 2/4 164/64/65	79.1 4/6 147/47/52	81.9 4/6 159/59/64	82.6 2/4 160/60/65	79.5 4/6 148/48/51	82.0 2/4 159/59/61	82.7 2/4 162/62/64
13	78.2 4/6 147/51/53	81.2 4/6 159/59/60	82.1 2/4 162/62/63	78.4 4/6 145/45/49	81.4 4/6 156/56/61	82.2 4/6 161/61/65	78.9 4/6 146/48/51	81.6 4/6 159/59/61	82.2 4/4 162/62/64
23	77.5 4/6 145/50/52	80.5 4/6 156/56/58	81.5 4/6 160/60/62	77.8 4/6 143/46/50	80.8 4/6 154/54/59	81.6 4/6 158/58/63	78.3 4/6 143/46/49	81.1 4/6 156/56/59	81.7 4/6 161/61/63
33	76.8 4/6 143/50/51	79.9 4/6 154/55/57	80.8 4/6 158/58/60	77.1 4/6 141/44/48	80.1 4/6 152/52/57	81.0 4/6 155/56/60	77.6 4/6 141/44/48	80.4 4/6 154/54/57	81.2 4/6 158/58/60
43	76.1 4/6 141/49/51	79.2 4/6 152/54/55	80.2 4/6 156/57/58	76.5 4/6 140/43/47	79.5 4/6 150/51/55	80.4 4/6 153/54/58	77.0 4/6 139/43/46	79.9 4/6 151/53/55	80.7 4/6 156/56/59
45	75.2 4/6 142/48/50	78.2 4/6 152/53/55	79.2 4/6 156/57/58	75.6 4/6 140/43/47	78.5 4/6 150/51/55	79.4 4/6 154/54/58	76.0 4/6 140/42/46	78.8 4/6 152/52/55	79.6 4/6 156/56/59
47	74.1 4/6 143/47/49	76.9 4/6 154/54/55	77.8 4/6 157/57/59	74.4 4/6 141/44/47	77.1 4/6 152/52/56	77.8 4/6 155/55/60	74.8 4/6 141/43/46	77.3 4/6 153/53/56	77.9 4/4 156/56/58

Fig. 1.
Paris Orly Airport RTOW Chart
Source: (AirSerbia)

Airport RTOW charts are calculated for every airport where certain airliner operates. It consists of general data such as aircraft engine type, airport elevation, take-off runway, runway surface condition and environmental data. This general data define which chart shall be used in take-off performance calculation. Relevant data used in model formulation is Operational Take-Off Mass (*OTOM*), decision speed (v_1) rotation speed (v_r) and safety speed (v_2). This relevant data is calculated and presented for different *OAT* values, flaps configurations and wind. For example, For *OAT* equals to 13°C, flaps configuration 2 and wind 0kt, *OTOM* equals to 81.4t, v_1 equals to 156kt, v_r equals to 156kt and v_2 equals to 161kt. Outside air density can be calculated from International Standard Atmosphere (ISA) tables (REF).
Effective wing surface and lift coefficient influence can be approximated with usage of sets of data points for different flaps configuration (Table 1, Fig.1).

Table 1
Airbus A319-100 flaps and slats configurations

Configuration	Flaps (°)	Slats(°)
0	**0**	0
1+F	10	18
2	15	22
3	20	22

Source: (A318/319/320/32 FCOM, AirSerbia)

In order to estimate the aircraft lift coefficient value, it is necessary to formulate the first moment of time during aircraft take-off roll where lift coefficient can be calculated. This methodology provides certain speed value which can be used in equation (1) in order to produce approximated lift coefficient value. During aircraft take-off acceleration, lift force grows, and in moment when aircraft lifts off, lift force is equal to aircraft weight. This moment is called lift-off moment and aircraft speed in this particular moment is named lift-off speed (v_{loff}). Lift-off speed can be approximated to be 10% greater than rotate speed. After defining input data, equation (1) can be formulated for aircraft take-off condition (eq. 2).

$$OTOM \cdot g = \frac{1}{2}\rho {v_{loff}}^2 S C_l \tag{2}$$

Utilization of equation (2), produces the aircraft lift coefficient values for different flaps settings. Since aircraft lift coefficient presents the measure of aerodynamic characteristics of an aircraft it can be determined for each take-off flaps configuration separately. For purposes of this model, we assume that take off runway is runway 08 on Paris Orly airport, ISA conditions, no wind and greatest aircraft mass possible which is *OTOM*. Since airport elevation equals to 277ft, in ISA conditions, *OAT* equals to 14°C. Outside air density can be calculated from ISA tables for determined *OAT*. In order to calculate *OTOM* and v speeds for different flaps configurations, it is necessary to interpolate between values for *OAT* equals to 13°C and *OAT* equals to 23°C, because there are no data for *OAT* equals 14°C in RTOW chart (Fig.1). Interpolated values of *OTOM*, v_1, v_r and v_2 are calculated and presented (Table 2).

Table 2
Interpolated values of OTOM, v_1, v_r and v_2 for different flaps configurations

Configuration	***OTOM*(t)**	**v_1 (kt)**	**v_r (kt)**	**v_2 (kt)**
1+F	81.13	158.7	158.7	159.8
2	81.34	155.8	155.8	160.8
3	81.55	158.7	158.7	160.8

After calculating and gathering all relevant data, lift coefficient values can be calculated by usage of equation (2). For *OAT* equals to 14°C, outside air density in ISA conditions equal to 1.212kg/m^3, v_{loff} is, as previously stated, equal to 1.1 times v_r which are already calculated (Table 2) and aircraft effective wing surface equals to 122.8m^2 (Airbus, 2015). For previously stated condition, lift coefficients equal to 1.319166 for flaps configuration 1+F, 1.372275 for flaps configuration 2 and 1.325995 for flaps configuration 3. High values of aircraft lift coefficient can be explained through great angle of attack during lift off and extended flaps and slats (Fillipone, 2008).

2.2. Aircraft drag coefficient calculation

Aircraft drag estimation is even more complex than lift estimation. Aircraft manufacturers rarely publish precise data regarded to engine power settings and aircraft drag. In this part of paper, the unique take off model, which can be used for different flaps /throttle setting in take-off performance calculation, is presented. The aerodynamic and engine data for this model is imported from FCOM published by aircraft manufacturer. In order to estimate aircraft drag coefficient, it is necessary do apply certain assumptions. Centre of gravity position does not have influence on drag value obtained from low speed polar. The aircraft take off mass change is small. We assume that aircraft mass during take-off is constant. Environmental conditions are *ISA* conditions, aircraft takes off from dry runway, no wind and no runway slope. Aircraft drag coefficient can be calculated from the distance required for acceleration during take-off equation. Distance to accelerate to rotate speed from *v=0* is calculated by utilization of eq. 3 (Mirosavljević et al., 2010).

$$1 = \frac{1}{2g}\int_0^{v_{rot}} \frac{dv}{\frac{T_n}{G} - \mu - \left(\frac{v}{v_{rot}}\right)^2\left(\frac{C_d}{C_l} - \mu\right)} \tag{3}$$

By usage of Wolfram Mathematica® 7.0 software, a feasible solution of eq. 3 is obtained by eq. 4.

$$L1 = \frac{1}{g}\left(-\frac{-C_l \cdot {v_{rot}}^2 \cdot log\left[C_; \cdot |G \cdot \mu - T_n| \cdot {v_{rot}}^2\right] + C_l \cdot {v_{rot}}^2 \cdot log\left[|C_l \cdot G - C_l \cdot T_n| \cdot {v_{rot}}^2\right]}{2(C_d - C_l\mu)}\right) \tag{4}$$

In eq. 4, *G* is aircraft weight, T_n is take-off net thrust for both engines in kN, μ is runway friction coefficient, C_d is aircraft drag coefficient and *L1* is required take-off distance. The (eq. 4) can be utilized for aircraft drag coefficient calculation because there is no significant difference in aircraft position in airflow from the point of rotation to the point of aircraft lift-off. Engines net thrust in this particular case is assumed to be maximum take-off thrust of an engine type IAE V2500-A1, which can be read from RTOW chart (Fig.1.) and Engine Performance Section in FCOM. Since there are two unknown variables in equation (4), which are aircraft drag coefficient C_d and distance required for aircraft to accelerate from v=o to v_r, it is necessary to assume the distance necessary for acceleration.

For the purposes of this model, it is assumed that aircraft needs 70% of Take-Off Runway Available (TORA) to achieve v_r speed. This data can easily be measured in exploitation and the model can be easily adjusted for the certain aircraft of interest for analysis. Runway friction coefficient can also be measured on the take-off runway. Therefore, with gathering input data process finished, it is possible to calculate aircraft drag coefficients for different flaps settings.

For the purpose of model validation, aircraft drag coefficients have been calculated for ISA conditions, dry runway and runway friction coefficient equal to 0.02, *OTOM*, *OAT* equal to 14°C, Maximum Net Take-Off thrust equal to 102480N per engine and distance to accelerate to rotate speed from $v=0$ equal to 2324m which is 70% of available runway 08 length on Paris Orly airport. For previously stated conditions calculated aircraft drag coefficient for flaps configuration 1+F equals to 0.231351, for flaps configuration 2 equals to 0.249037 and for flaps configuration 3 equals to 0.229921. Estimated drag values for different flaps configuration are greater than usual values due to extended flaps.

2.3. Aircraft performance degradation influence analysis

In this section of the paper, the analysis of aircraft drag increase on required take-off field length is presented. After determination of aircraft lift and drag coefficients, it is possible to perform aircraft drag variation in order to estimate its influence on distance required for aircraft acceleration from v equals to 0 to v_r. The aircraft drag values are increased to 15% total with increment 0.5%. For different flaps configuration, the influence of aircraft drag increase on required take-off field length is determined by calculating each point separately (4). After calculating sets of data points it is possible to graphically present the results (Fig.2.).

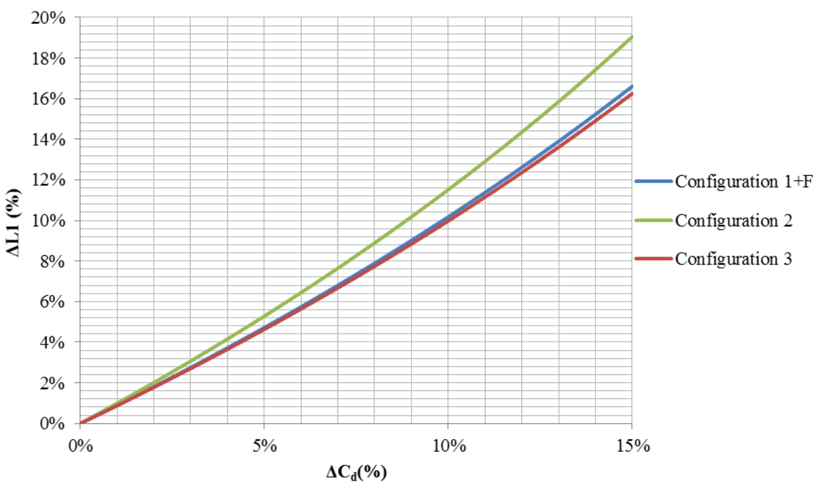


Fig. 2.
Deviation of required runway length for achieving v_r ($\Delta L1$) with aircraft drag increase (ΔC_d)

After determining sets of data points it is possible to determine the fitting functions for each flaps configuration by usage Microsoft Excel® software. The fitting functions are quadratic equations with determination coefficients values close to 1. The fitting function of aircraft drag increase influence on required runway distance to achieve v_r for flaps configuration 1+F is named $L1_{corr1+F}$ (5), for flaps configuration 2 is named $L1_{corr2}$ (6) and for flaps configuration 3 is named $L1_{corr3}$ (7).

$$L1_{corr\ 1+F} = 3955.1 \cdot \Delta C_x^{\ 2} + 1965.8 \cdot \Delta C_x + 2325 \tag{5}$$

$$L1_{corr\ 2} = 5207.9 \cdot \Delta C_x^{\ 2} + 2149.7 \cdot \Delta C_x + 2325.5 \tag{6}$$

$$L1_{corr\ 3} = 3787.4 \cdot \Delta C_x^{\ 2} + 1397 \cdot \Delta C_x + 2325 \tag{7}$$

Previously stated equations indicate that required take-off runway length increases with aircraft drag increase. This practically means that aircraft needs greater runway length for take-off than calculated by usage of FCOM which leads to a conclusion that safety of an aircraft and its passengers can be compromised if aircraft performance degradation is not analysed. Required take-off runway length increase has direct influence on initial climb gradient which leads to a conclusion that there is probability that aircraft won't be able to achieve minimum obstacle clearance altitude. On the other hand, greater aerodynamic drag value leads to less quantity of available engine thrust which leads to decreased

airspeed values. Decreased airspeed values have direct influence on aircrafts safety, especially in cases when airspeed is close to stall speed.
Since rotate speed v_r and decision speed v_1 are in most cases equal, this particular analysis can be implemented in situations when one engine fails during take-off process. Aircraft drag increase, increases the runway length necessary to achieve decision speed. This leads to a conclusion that aircraft has less runway length available to perform full stop after one engine failure. Even if pilot performs full braking, it is questionable that aircraft can perform full stop before the end of runway.
In a situation when pilot decides to continue take-off after one engine failure, initial climb gradient with one engine inoperative has less value than climb gradient with all engines operative which leads to a conclusion that there is probability that aircraft won’t be able to achieve minimum obstacle clearance altitude during initial climb.
Previously stated facts indicate that aircrafts safety will be compromised if aircrafts performance degradation exceeds certain calculated limits. For this reason, in order to maintain aircraft safety on a satisfactory level, it is necessary to perform detail analysis of performance degradation for each aircraft in fleet with data gathered from real aircraft flights. This methodology allows operator to calculate real aircraft performance and prevent aircraft safety endangerment.

3. Conclusion

Aircraft performance degradation has negative influence on aircraft exploitation quality in several different manners. In order to overcome additional drag, which is consequence of ageing aircraft and its exploitation, it is necessary to generate additional thrust which reduces excess thrust margin. In flight regimes where engine runs close to its full potential, aircraft performance degradation can lead to loss of airspeed due to lack of excess thrust. Additional thrust generation leads to increased fuel consumption which leads to greater exploitation costs. Additional fuel necessary to overcome aircraft performance degradation issue, reduces maximum payload which has direct influence on income.
Aircraft performance degradation has direct impact on aircraft safety. Increased drag increases required runway take-off length and decreases climb gradients of an aircraft in cases of all engines operative and one engine inoperative. Increased drag increases fuel consumption which is also a safety issue.
Beside safety issues caused by aircraft performance degradation, it is necessary to mention operational issues caused by performance degradation. Operational issues caused by negative influence of aircraft performance degradation are technical delays, return to ramp or aborted take-off which can lead to operational disruption of flights schedule and loss of income in case of cancelled flights.
The impact of aircraft performance degradation on the safety of aircraft operations can be reduced by creating adequate procedures, by performing revisions of flight operations manual on the basis of data collected from practice, adequate training of staff which handle the aircraft, equipment and other systems that are in contact with the aircraft as well as staff training for emergency cases. Constant monitoring of the degradation of aircraft performance helps optimize the maintenance plan of an aircraft, maintaining a high level of aircraft safety, and to perform optimization of flight parameters in order to reduce the aircraft exploitation costs.

References

Air Serbia. 2011. *A319 - 100 Flight Crew Operations Manual* (1st ed.). Belgrade.
ATSU. 2007. *The impact of ageing aircraft on aviation safety.* Canberra: Australian Transport Safety Bureau. Available from Internet: <https://www.atsb.gov.au/media/29959/b20050205.pdf>.
Cavcar, A.; Cavcar, M. 2004. Impact of aircraft performance differences on fuel consumption of aircraft in air traffic environment, *Aircraft Engineering and Aerospace Technology*, 76(5): 44-58.
Čavka, I.; Mariani, M.; Mirosavljević, P.; Abbondati, F.; Čokorilo, O. 2014. Learning From Errors – Case Study of an Aircraft Accident. In *Proceedings of International Conference on Traffic and Transport Engineering*, Belgrade 27-28 November, Serbia, 444-450.
Čokorilo, O.; Gvozdenović, S.; Mirosavljević, P.; Vasov, L. 2010. Multi Attribute decision making: Assessing the technological and operational parameters of an aircraft, *Transport*, 25(4): 352-356.
Čokorilo, O.; Mirosavljević, P.; Gvozdenović, S. 2011. An Approach to Safety Management System (SMS) Implementation in Aircraft Operations, *African Journal of Business Management*, 5(5): 1942-1950.
Čokorilo, O.; De Luca, M.; Dell’Acqua, G. 2014. Aircraft safety analysis using clustering algorithms, *Journal of Risk Research*, 17(10): 1325-1340.
EASA. 2015. *Annual Safety Report.* Cologne, Germany: European Aviation Safety Agency.
Ford, T. 1998. Rejected take-off and landing. *Aircraft engineering and Aerospace Technology,* 70(6): 23-35.
ICAO. 2015. Safety Report. Montreal: International Civil Aviation Organisation. Available from Internet: <http://www.icao.int/safety/Documents/ICAO_Safety_Report_2015_Web.pdf>.
Filippone, A. 2008. Comprehensive analysis of transport aircraft flight performance, *Progress in Aerospace Science,* 44: 192-236.
Mirosavljević, P.; Gvozdenović, S.; Čokorilo, O.; Vasov, Lj. 2011. The Turbofan Transport Aircraft Pollution Calculation Software. *REACT 2011 The International Conference on Climate Friendly Transport*, Belgrade, Serbia, May 16-17.
Speyer, J.J. 2001. *Getting hands on experience with aerodynamic deterioration*, FAST Airbus Technical Digest,

Toulouse Blagnac, France.

ESTIMATED COST-BENEFIT ANALYSIS OF RUNWAY ACCIDENT SEVERITY REDUCTION BASED ON ACTUAL EMAS ARRESTMENTS

Rob van Eekeren[1]
[1] Safe-Runway GmbH, Germany

Abstract: Is next to preventing a runway excursion also mitigating the outcome / severity of a runway excursion a cost effective method in reducing the risk? In the automotive industry has increasing the survivability of an accident become a voluntarily industry standard. Survivability enhancements in aircraft are due to weight and emission limitations very limited. However infrastructural mitigations at aerodromes are possible in line with current ICAO and the competent authorities guidelines. Are the investments in runway infrastructures that increase survivability enhancements, justified when related to potential safety benefits and the associated costs? Some aerodromes believe not and have non-standard runway safety area's. This paper analysis runway overrun accidents into a non-standard runway end safety area, however equipped with engineered material arresting system as mitigation. These runway-overrun accidents are analyzed and accidents costs are estimated. The accident costs consist of damage; operational; opportunity; injuries and the indirect safety costs. For human injuries a method is defined based on the costs of the accident injury score. At the same time are the costs estimated in the hypothetical case that EMAS would not have been installed. The difference, compensated for the worldwide installation costs, provides a cost-benefit indication. The total net savings are estimated at one Billion $. The law of diminishing returns poses a financial limit to limit to future runway overrun preventions. It is concluded that mitigating certain runways by bringing a non-standard runway end safety area either up to standard or mitigate it to an equivalent level of safety, is a cost effective method to reduce the risk for human life's, injuries, property and equipment.

Keywords: runway safety, RESA, EMAS, cost-benefit, ALARP overruns, excursions.

1. Introduction

An Airbus A340-300, landed in severe thunderstorm conditions in heavy rain, touching down approximately halfway down the non-grooved runway at Toronto Pearson International Airport, Ontario, Canada. The aircraft did not stop before the runway end and overran into a ravine. The runway did not contain a standard runway safety end (RESA). 12 out of the 309 people on board received injuries. Impact forces and a post-impact fire destroyed the aircraft.
What are the accidents costs now, what would these have been with a full RESA and would that have justified an investment in a RESA or equivalent?

The EAPPRE aims at preventing runway excursions, however with close to 50% of aviation accidents and fatalities occurring on or near the airport a certain rest risk will always remain (BOEING Statistical summary). Figures over the period 2011-2014 indicate no significant drop as compared to the 1995-2008 (NLR-ATSI; FSF). Aviation traditionally has always successfully focused on prevention, due to the non-survivability aspect of airborne accidents. However ground based accidents could in principle also be survivable with the right severity reducing mitigations.
The costs of preventing an accident (COI) rise exponentially when the chance becomes extremely low (p^{acc}). The costs of Investment (COI) rise exponentially, while gains from investment (GFI) remain the same. Thus the return on investment (ROI) of only preventing measures will become negative with a decrease of the accident probability (law of diminishing returns). Therefore is it to be expected that the costs associated with prevention will at a moment pose financial limits to further increasing safety. Could reduce the severity of a ground based aviation accident be cost effective and thus provide an additional method in reducing the risk?

$$\left\{\frac{GFI}{\lim_{\text{pacc}).\ 0}} => \infty COI\right\} \text{ and } \frac{(GFI-COI)}{COI} = ROI \tag{1}$$

The costs related to a runway excursion risk could, when combined with a probability calculation, provide a solid motivation if investing in a RESA (or equivalent) is cost effective. This additional approach could potentially save human lives, reduce the number and level of injuries, save aircraft and reduce the damage to equipment and property.

2. Runway overrun risk mitigation by RESA

Risk is a function of Probability and Severity of an occurrence. Combining these two separate elements provides an indication of risk.

Risk = f{Probability|Severity}

Safety Management Systems are capable of identifying and mitigating the possibility of an occurrence. ICAO doc 9859 describes the management flow, including identifying the hazard, the consequences and as a result the risk. The result of an overrun is mitigated by a RESA. The Runway End Safety Area (RESA) intends to reduce the risk of damage to an

[1] Corresponding author: robvaneekeren@safe-runway.com

aeroplane undershooting or overrunning the runway. It provides that protection up to 90 meters and as far as practicable up to 240 meter (code 3 or 4) or 120 meter (code 1 or 2) additional to the runway strip length of 60 meter at the runway end (ICAO annex 14 § 3.4-3.5). That provides thus a minimum length of 150 meters and as far as practicable 300 meters for aircraft undershooting or overrunning the runway. Research by the FAA (1975-1987) indicates that a 1000 feet RSA is expected to stop 91% of overrunning aircraft (Dry RESA).

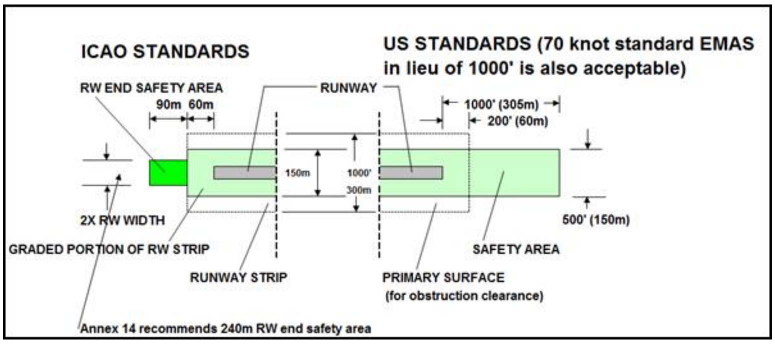


Fig. 1.
RESA & EMAS
Source: Zodiac Arresting systems

An FAA tested and approved method to compensate inadequate Runway Safety Area's (RSA) is Engineered Material Arresting system (EMAS). In order to provide an equivalent level of safety for those runways not having a full RSA, provides Engineered Material Arresting Systems (EMAS) a unique form of overrun protection for airports. Placed at the end of a runway in the form of a bed that crushes under the weight of an aircraft, the EMAS decelerates the aircraft and brings it to a safe stop within the overrun area (70 knots entry design speed limit of most critical aircraft). It intends to provide an equivalent level of safety compared to a full RESA. EMAS is installed on over 100 runways world-wide and has successfully and safely stopped aircraft. Arrestment's show very little or no minor damage to the arrested aircraft and no injured people or fatalities at all. EMAS is a generic term and is at the moment produced by four different manufacturers using three different techniques.
Contracting states have agreed to follow ICAO Standards and recommended Practices (SARPS) and needed to transfer these into their own national laws to become effective. Here start variations in interpretations. EASA, by example, almost copied the ICAO text in their regulation however with a vital difference: The replacement of "shall" into "should", changing an ICAO standard into a recommendation on RESA requirements. This leads to various interpretations and levels of safety and thus standards to be achieved.

2.1. ALARP

EASA Safety Risk Management (EASA NPA 2015-18(B)) describes As Low As Reasonably Practicable (ALARP) as "*Showing that the safety risk is ALARP means that any further risk reduction is either impracticable or grossly outweighed by the cost*".

Determining the ALARP of RESA is thus depending on the interpretation of aircraft operators, aerodrome operators, ANSP's as well as of the interpretation of the 28 EASA member states. ALARP is a function of safety, practicality and financial arguments. Financial repercussions of runway accidents can therefore be used as a common factor in Risks.

The consequences of a runway excursion for an ANSP might be re-routing and temporarily delays; for an aerodrome operator could it result in the temporarily closure of a runway, damage to equipment and handling of the occurrence; whilst an aircraft operator could loose an aircraft, be faced with full passenger compensations and severe financial and reputational repercussions.

$$\mathbf{ALARP} = \boldsymbol{f}\{\text{Safety gain, Practibility, } \mathbf{Costs}\}$$

For non-standard RESA's has EMAS the potential to reduce the runway excursion risk through specifically mitigating the severity aspect of a runway overruns. Analysis of cost-benefit of full RESA or EMAS provides an indication if runway overruns ALARP levels is cost effectively achievable.

2.2. Costs

2.2.1. Human

Injuries. Cavka and Cokorilo (2012) provide a method of calculating the cost benefit of aircraft safety, relate direct safety costs (DSC) to indirect safety costs (ISC), conclude that the financial losses are lower when timely the safety risk is determined and used Eurocontrol figures on injury calculations. These however do not differentiate the levels of injuries. The AIS Abbreviated Injury Scale (AIS) is coordinated with the medical sector and is since 1980 an accepted international method for trauma scoring in transport. Combining the number of injuries per AIS code with an average on medical treatment expenses per code would provide an indication of the injury costs per accident. Various papers on the costs of road traffic traumas indicate the cost for AIS (Zaloshnja, 2004; Ching-Huei). The US Economic counsil to the transportation Industry released in 2001 a system and figures based on the AIS. These figures are in line with other calculations. Costs other than Willingness To Pay (WTP) such as emergency services, medical care and legal and court services (excluding the costs of settlements) are to be added on an individual basis to the WTP values. Postma (2014) concluded that improved protocols are needed to counter the challenges of treating the sudden and large numbers of injuries in aviation accidents. Secondary effects to hospitals confronted with a sudden large number of victims are not enough taken into account yet.

Fatalities. In the period 1975-2014 a total of 17.558 people died due to air crashes averaging 439 people per year, Comparing the 4 decennia (1975-1984: 236/yr; 1985-1994: 506/yr; 1995-2004: 555/yr; 2005-2014: 459/yr) show no noticeable reduction in absolute numbers. However in the same period have the flown passenger kilometers quadrupled. It is therefore concluded that safety gain successfully compensates the growth in aviation traffic.
The 1999 Montreal (MC99) conventions established a modern compensatory regime in respect of passengers who suffer death or injury caused by an accident during international air carriage. It indicates a compensation of approximately $170 K per fatality. Kakalik et al. concluded that an average of $421 K are the real paid expenditures per aviation casualty. The cumulative US$ inflation since 1988 is 103,5%, leading to a 2015 compensation of $856,7K$. The 2001 ASTER report and Cavka and Cokorilo (2012), refer to the Value of Statistical Life (VOSL) and WTP for the European countries. These vary (1998) between 0,65M€ (Estonia) and 2,64M€ (Luxemburg). Applying inflation correction to the VOSL would give 2,96M€ (336 M$). The Economic counsel to the Transportation Industry (ECTI) advised the FAA in 2007 to use 3 M$ per casualty (+ 132K for WTP).

Conclusion - It can therefore be concluded that scoring aviation accident victims in accordance with the AIS provides a basis for estimating the severity of an accident. The costs are underestimated due to inflation correction and the lack of third party costs, such as the consequences of sudden treatment of large numbers of victims. No inflation for this paper is justified since a number of the researched runway excursion accidents occurred during the past 2 decades. Since all EMAS arrestments have been in the USA, are for this paper the FAA figures taken.

Table 1
AIS aviation costs

AI Co	Injury	Example	AIS % prob death	Total costs (200 dollars)
1	Minor	Superficial laceration	0	$10.500
2	Moderate	Fractured sternum	1 – 2	$55.600
3	Serious	Open fracture of humerus	8 – 10	$193.700
4	Severe	Perforated trachea	5 – 50	$703.100
5	Critical	Ruptured liver with tissue loss	May-50	$2.587.500
6	Maximum	Total severance of aorta	100	$3.123.700

Source: Economic values for FAA investment and regulatory decisions, contract nr DTFA 01-02-C00200

2.2.2. Direct Safety Costs (DSC)

Both, Cavka and Cokorilo (2012) and ASTER, relate the DSC of an accident to the severity of the accident, the aircraft type and the aerodrome involved. ASTER differentiates and relates the severity classification depending on the level of damage to the aircraft and the number of fatalities. Although this table needs to be reviewed and updated *(e.g. it is doubtful if 50% damage to a A380 resulting in over $200 million damage, with 500+ injured passengers would still be classified as a "moderate" accident),* is the severity classification by ASTER taken as the best available at this moment.

Table 2
Aircraft damage levels definition

Level	Dama	Dea
Minor	15%	0
Moderate	50%	0
Major	80%	0
Disaster	100%	30%
Catastrophic	100%	50%

Source: ASTER consolidated report

The aircraft damage costs depend on the Current Market Value (CMV), which is a function of list price and age. Some publications use a generic figure averaging at 13% for the restorations costs of aircraft. NLR-ATSI differentiates and relates the aircraft repair costs to the level of damage: Minor 15%; Moderate 50%; Major 80%, Disaster and Catastrophic 100% of the aircraft CMV. ASTER estimates a loss of resale value between 5% and 10% of an aircraft involved in an accident, which obviously does not apply to full hull losses (Disaster and Catastrophic).
The accident aircraft needs to be replaced in order to maintain the same production capability during its downtime, that requires leasing an equivalent type. The price thereof varies with market availability, age and type. The monthly lease rates vary between 1.6% and 3,7% of the CMV. For simplicity is the lease price based on a 5 year-old aircraft (63% CMV and 2.0% monthly lease). Airline costs for not being able to provide planned production is estimated at 360k$ (wide body) and 150k$ (narrow body) per day. This is valid until the moment a lease aircraft resume production. For a wide body aircraft results that in approximately 3,8M$ and for a regional aircraft 1,25M$ per month. Business type aircraft are regarded as narrow body.
A runway excursion results in a closure of the runway resulting in delays and diversions. ASTER estimates the airline ground delay costs at € 22 per minute and € 33 per minute in the air. These are in the same range as the US FAA figures. Assuming an average of 40 departures per hour per runway are the ground delay costs estimated at 53k$ per hour.
IATA estimates the total diversion costs at 15k$ (narrow body) and over 100K$ (wide body) per aircraft. Diversion effects all aircraft inbound to an unforeseen closed runway. Aircraft not yet departed can be rerouted to an alternative destination; these are thus less affected. The diversion costs vary therefore between an estimated 600k$ (regional airport) and 20M$ (major hub). Diverting to another runway or airport causes also third party delays and additional safety risks. The extra costs associated with third party delays and the extra safety risk for diverting aircraft (low fuel, last minute re-planning, etc.) are not taken into account.
The costs of a runway excursion for an aerodrome include the costs for repair and not being able to use the runway for a certain (unexpected) time. Direct aerodrome repair costs include damage to runway and its surroundings (strip, RESA, EMAS, lights, (frangible) equipment, etc.). Additional costs such as removal of the wreckage, fire brigade, legal etc. are excluded in the DSC. Third-party repair costs (e.g. the TAM at Congonhas, warehouse and gas station), are also excluded in the DSC. No open source information on aerodrome direct repair and third party costs has been found, thus these are not rated in this paper (NR).
The opportunity costs consist of not being able to use the high value production asset: the runway. E.g. landing fees, passenger fees and taxes at major airports are estimated at $ 5k per aircraft. Having to close a runway could realistically cost up to $ 4,0M (50 movements /hour/ runway) per day (16 hours) for a major hub airport. The costs for regional airport is estimated at 200 K$ ($1k per movement/ 200 movements per day) for a regional airport. ASTER relates the runway closure to the accident severity: Minor 2 days, Moderate 2 days, Major 4 days, and Disaster and Catastrophic 5 days. These ASTER figures are used in this paper, although further research might provide an updated and more precise indication.

At 4th March 2015, veered Turkish airlines A330-300 of runway 02 of Kathmandu, collapsing the nose wheel, resulting in 4 minor injuries. Kathmandu closed the runway 02 for 3 ½ days.

EU Regulation 261/2004 regulates financial compensation for flight delays. These vary, depending on the type of flight and delay from € 250, €400 to € 600 per passenger. It might seem reasonable that accidents and or incidents would be excluded from passenger delay compensation. However jurisprudence on technical failures and birdstrikes indicates that passengers might also become eligible for compensation. The number of passengers affected is dependent of the type of flight, regional/intercontinental and number of daily flights (in and outbound) scheduled for the accident aircraft. It is assumed that regional flights have an average load of 100 passengers with 6 stretches per day and intercontinental flight 2 stretches, carrying 300. Thus the affected number passengers per day eligible for compensation are approximately the same and related the accident severity. Lost baggage compensation related to the severity of the accident is taken from Cavka and Cokorilo (2012).

Table 3
All DSC in one table

Classification	MINOR	MODERATI	MAJOR	DISASTER	CATASTROPHI
Loss of aircraft prodı	2 days	2 days	4 days	5 days	5 days
Lease time needed	2 months	2 months	4 months	5 months	5 months
Loss of resale value	7,50%	7,50%	7,50%	NA	NA
Narrow body M$, mı	2,5M$	2,5M$	5,0M$	7,5M$	7,5M$
Operational costs	600K$	600K$	600K$	600K$	600K$
Wide body M$, mon	7,6M$	7,6M$	15,4M$	19M$	19M$
Operational costs	20M$	20M$	20M$	20M$	20M$
Extra cost	NR	NR	NR	NR	NR
Runway closure	2 days	2 days	4 days	5 days	5 days
Repair	NR	NR	NR	NR	NR
Downtime Regional	400K$	400k$	800k$	1,0M$	1,0M$
Downtime Major Hu	8,0M$	8,0M$	16,0M$	20,0M$	20,0M$
Loss of baggage com	NA	NA	210K$	210K$	210K$
Passenger compensa	250$	400$	600$	600$	600$
Number of passenge	600	600	600	600	600
Number of days	2	2	4	5	5
Total passenger com	300k$	480k$	1,44M$	1,8m$	1,8m$

Source: Safe-runway GmbH

2.2.3. Indirect safety costs (ISC)

ISC relates to the investigation costs, search and rescue, recovery, legal and third party costs, loss of investment income, loss of reputation, increase of insurance premium, loss of business due to PR, etc. Various methods are available for calculating these. One method is to calculate each factor separately as provided the economic counsil to the US transportation Industry the FAA accident investigation costs. Although certainly possible to list all elements separately, used Cavka and Cokorilo (2012) a more practical approach by relating the Indirect Safety Costs (ISC) to the Direct Safety Costs (DSC) depending on the severity of the accident, which is used in our model.

Table 4
ISC-used - Indirect Safety Costs as a function of Direct Safety Costs

Classification	MINOR	MODERAT	MAJOR	DISASTEF	CATASTROPHI
ISC as a function of DSC	5%-15%	25%-40%	50%-70%	85%-110%	90%-140%
Median ISC as a function of DSC	10% DSC	32,5% DSC	60% DSC	97,5% DSC	115% DSC

Source: (Safe-runway GmbH)

Miscellaneous costs such as loss of company share value fines, punitive damage, criminal proceedings, extra legal costs, third party compensation fees, environmental fees, etc. are therefore not taken into account due to lack of sufficient data.

2.3. Cost-benefit of EMAS

10 Actual EMAS arrestment's provide an indication on the cost-benefit by comparing the financial consequences what would likely have happened in the hypothetical case that EMAS would not have been installed with the estimated costs of the actual arrestment's. The human costs, DSC and ISC are calculated for both scenarios are calculated based on the known specifics of the accident and using the assumptions as described.

The Toronto overrun as an example:
An 6 years old A340 overran runway 24L at Toronto Pearson with a speed of 86 knots, destroying the aircraft in a ditch / ravine. Toronto had no standard RESA, nor an EMAS bed. All 10 overruns into EMAS have been with very minor to almost no damage to the aircraft and no risk to the passengers/crew. A standard EMAS bed is designed for an entry speed of 70 knots for the most critical aircraft normally using the aerodrome. Let 's assume that the A340 would have vacated the EMAS bed with some speed, but less than 70 knots. It is very likely that enough energy would have been disseminated to cause only minor damage to the aircraft also. Calculating the runway excursion costs for this accident results in a total of 468,96 million$. Assuming there would have been an EMAS bed installed, the severity would have shifted from Disaster to Minor resulting in (hypothetical) accident costs of 67,21 million$. In the assumption that the aerodrome would have invested 10 M$ for an EMAS bed on runway 24L, the net savings would have been 401,75M$-10,0M$ over 390 million $.

Based on the available accident reports and FAA or open source document material are, as reasonably as possible, assumptions made in order to get to a reasonable indication of the possible consequences what could have happened if EMAS would not have been installed. These are than classified in line with ASTER into severity levels MINOR, MODERATE, MAJOR, DISASTER or CATASTROPHIC. All EMAS arrestment have been classified in the minor category, leading sometimes to overestimating the financial consequences. (e.g. a runway closure of 2 days (minor category) was in a number of cases only a matter of hours). Nevertheless is for the uniformity of the calculations the same method applied to all.
When data on consequences are clear from either the NTSB or the FAA report, these figures are taken. When not, then assumption are made to the best available most likely reasonable estimate. When more accurate data would become available, the calculations can be adapted accordingly.

Table 5
Estimated EMAS overrun costs

Occurrence	estimated costs with EMAS	Hypthetical costs without EMAS	Motivation
May 99 KJFK, SAAB34	Minor: $ 34	Disaster $ 229	high speed; Thurston Basin; substantial damage to aircraft, critical injuries, SOB 29
May 03 KJFK MD11	Minor $ 70	Disatster $ 263	low speed; before Thurston Basin; substantial damage to aircraft, major injuries, SOB 3
Jan 05 KFFK B747	Minor $ 73	Disaster $ 405	high speed; Thurston Basin; substantial damage to aircraft, critical injuries, SOB 3
Jul 06 KGMU Falcon900	Minor $ 13	Major $ 59	low speed; serious damage, serious injuries SOB 5
Jul 08 KORD A-320	Minor $ 55	Major $ 292	low speed knots; major damage, serious injuries SOB 145
Jul 08 KCRW CRJ200	Minor $ 10	Catastrophic $ 292	medium speed, ravine, destroyed, all fatalities SOB 34
Oct 10 KTEB Gulfstream 4	Minor $ 11	Disaster $ 107	medium speed, substantial damage, serious injuries SOB 10
Nov 11 KEYW Cessna 550	Minor $ 6	Disaster $ 46	medium speed, substantial damage, critical injuries SOB 5
Oct 13 KPBI Cessna 680	Minor $ 8	Major $ 34	low speed, major damage, serious injuries SOB 8
Jan 16 KPWK Falcon20	Minor $ 3	Major $ 20	Medium speed; highway; substantial damage SOB 2
Oct 16 KLGA B737	Minor $15	Disaster $ 276	Medium speed, external casualties at central parkway, SOB 48.

Source: (Safe-runway GmbH)

The total estimated costs (Million $) without EMAS are just over 2000, whilst the estimated accident costs are close to 300; thus 1700 has been saved. Standard investment in EMAS is estimated at 5-7, totaling the World Wide EMAS installations costs at 700, resulting in $1000 Million of net savings.

3. Conclusion

Combining the probability of a runway excursion with the financial consequences provides a concrete tool in a safety management system to address a specific runway excursion risk and bring that to the ALARP level. It seems that the duration of runway closure as used in this paper, derived from the ASTER logic, might not be accurate enough. Further research is recommended on the runway-overrun costs including all types of aircraft and aerodromes to derive to more precise data.
Nevertheless is the conclusion justified that mitigating the outcome of a runway overrun by a full 300 meters RESA or equivalent could be cost effective. The financial repercussions of a runway excursion are considerably larger for aircraft operators than for an aerodrome operator or an ANSP. Since aerodromes have to invest in a full RESA or equivalent, whilst the major financial benefits are for others, the decision making process to invest in this severity safety

enhancement is not optimal. The estimated net savings of $ 1 Billion for the industry as a whole justifies a joined approach. It is therefore recommended that the competent authority stimulate stakeholders to jointly find cost effective solutions for non standard RESA’s.

Acknowledgements

Special thanks to Benoit Larrouturou of Zodiac Aerospace Arresting Systems, Gerard van Es of the NLR-ATSI, dr Olja Cokorilo, Belgrade University and dr Stephen Wright, University of Leeds for their contributions and patience.

References

Airfleets. Available from Internet: <http://www.airfleets.net/crash/fatalities_year.htm>.
Airliners.net aircraft values. Available from Internet: <http://www.airliners.net/forum/viewtopic.php?t=587137>.
AIS description. Available from Internet: <https://en.wikipedia.org/wiki/Abbreviated_Injury_Scale>.
AIS unification: the case for a unified injury system for global use; J trauma, 1999.
ASTER consolidated report; Available from Internet: <http://www.transport-research.info/sites/default/files/project/documents/20100310_120301_24152_Aster%20Consolidated%20Final%20Report.pdf>.
BOEING Statistical summary. Available from Internet: <http://www.boeing.com/resources/boeingdotcom/company/about_bca/pdf/statsum.pdf>.
Cavka, I.; Cokorilo, O. 2012. Cost - Benefit Assessment of Aircraft Safety, *International Journal for Traffic and Transport Engineering*, 2(4): 359-371.
Ching-Huei, L. A method to estimate injury medical costs of occupants in a crash test.
Convention for the unification of certain rules for international carriage by air; Montreal 28 may 1999. Available from Internet: <http://www.inflationdata.com>.
EAPPRE. Available from Internet: < http://www.skybrary.aero/index.php/European_Action_Plan_for_the_Prevention_of_Runway_Excursions_(EAPPRE)>.
EASA ADR-DSN. Available from Internet: <https://www.easa.europa.eu/certification-specifications/cs-adr-dsn-aerodromes-design>.
EASA CS-ADR-DSN Aerodromes. Available from Internet: <https://www.easa.europa.eu/certification-specifications/cs-adr-dsn-aerodromes-design>.
EASA NPA 2015-18(B). Available from Internet: <https://www.easa.europa.eu/system/files/dfu/NPA%202015-18%20(B).pdf>.
EMAS, arrestments booklet. Available from Internet: <http://www.safe-runway.com>.
FAA advisory circular 150/5220-22A 9/30/2005.
FAA factsheet EMAS. Available from Internet: < https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=13754>.
FSF reducing the risk of runway excursions. Available from Internet: <https://flightsafety.org/files/RERR/fsf-runway-excursions-report.pdf>.
GRA incorporated, economic values for FAA investment and regulatory decisions. Available from Internet: <https://www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/050404%20Critical%20Values%20Dec%2031%20Report%2007Jan05.pdf>.
IATA pre crisis forecast. Available from Internet: <https://www.iata.org/whatwedo/Documents/economics/IATA_Economics_Briefing_Impact_of_Recession_Dec08.pdf>.
IATA, IATA diversion management, Geneva, 2014. Available from Internet: <http://www.iata.org/whatwedo/workgroups/Documents/ACC-2014-GVA/occ-5-diversion.pdf>.
ICAO annex 14. Sixth edition 2013.
ICAO doc 9859 SMM 2013. Available from Internet: <http://www.icao.int/safety/SafetyManagement/Documents/Doc.9859.3rd%20Edition.alltext.en.pdf>.
ILE Postma: “Brace For Impact! A thesis on medical care following an airplane crash”, 2014.
Kakalik, J.S. Costs and compensation paid in aviation accident litigation, ISBN 0-8330-0909-5.
NLR-ATSI. Available from Internet: <http://www.nlr-atsi.nl/services/runway-safety/runway-excursions/index.html>.
Rosen, E. 2009. Pedestrian fatality risk as a function of car impact speed.
The telegraph. Available from Internet: <http://www.telegraph.co.uk/travel/news/Passengers-delayed-by-bird-strikes-can-claim-compensation-judge-rules/>.
Zaloshnja, E. 2004. Comprehensive and human captital crash costs by maximum police reported injury severity within selected crash types.

SESSION 2: HUMAN FACTOR IN TRANSPORT SYSTEMS

INSURANCE IN TRAFFIC AS AN ELEMENT OF INTELLIGENT TRANSPORT SYSTEMS - INFORMATION ASPECT

Barbara Rudić[1], Marko Pogarčić[2], Ivan Pogarčić[3]
[1,3] Polytechnic of Rijeka, Vukovarska 58, Croatia
[2] Municipal Court of Rijeka, Zrtava fasizma 3, Croatia

Abstract: ITS as an intelligent integral system equally implicit a complex structure of information system, as a functional format of real / material ITS. Pragmatically defined, the interest and need for quality ITS lies in transport stimulated problems and possibilities of usage of new information technology. That is why ITS could be defined as a holistic, controlled, information and communication version of a real system. Specific and unique possibilities which ICT provides in the domain of transport and traffic lie in the possibility of simulation with virtual models of real systems. Modelling and simulation of real system provide the creation of database. It can be used for describing situations which did not happen e.g. as a forecast. ITS is equally important in political elements of society safety. Surveillance of routes is important not only for safety of countries, but it is significant globally. ITS can be observed as a change in paradigm which is present in development of traffic discipline and in technology of transporting people and goods. ITS is a systematic managing and ICT solution which is (or it can be) incorporated in the network infrastructure, vehicles, monitoring centres and different ICT devices. This research examines information aspects of ITS in securing, measures and activities that can increase safety in transport. Types of insurance and compensation in traffic accidents are described, considering organizations that provide insurance in traffic. Insurance contract is considered through its concept, principles, participants and the insurance policy as a proof of insurance contract. This research analyzes the need for software solutions for insurance companies that complete ITS entirely. That is the only way to provide holistic accent of integral transport system. .

Keywords: ITS, ICT, traffic accidents, control of roads, traffic insurance contract.

1. Introduction

Transportation as economic activity is constantly developing, especially the road transportation. An impact of the road transportation on all human activities and its importance are relevant facts. That's why the transportation has an important role in modern society. There are different properties which can be treated apart when talking about the transportation. However, even when observing different features separately, a holistic approach should be considered and demanded (implemented, applied). Security problems in transportation will be examined separately from professional technological and legal viewpoints in this paper. To partially ensure a holistic picture, both viewpoints mentioned above are shown as one unit through basic settings of ITS which is a modern approach to transportation, and it necessitated the creation of integral information system. The integral information system isn't used in the flat- rate meaning, but it entails a complete integration of pieces of information related to core activities in the transportation with pieces of information that are important for all collateral activities on which the transportation as an activity relies. To be clear: security problems or for example traffic accidents have their material weights, but collateral facts/ information/ data can be relevant to some other activities. Permanent database establishment which can be updated and modified can be relevant for the broader social community. As mentioned, authors are interested in possibilities and specific conditions on a, conditionally speaking market, the opportunity to both using and providing pieces of information related to traffic safety from technological and legal viewpoints. There is a strong connection between insurance as a professional activity and transportation as an industry, in particular through the traffic of people and good insurance system. The road transportation safety will be examined apart while stating the main factors that influence the road transportation security and also insurance whose role is to enhance the traffic safety.

2. Defining the framework

The starting framework of this research is based on the definition and properties of the Intelligent transportation systems (ITS). ITS represents a combination or at least an intention to combine Information and communications technology (ICT) and transportation technology. Both mentioned technologies are components in function of factors management which are mutually intertwined and affect each other. Roads, vehicles, traffic regarding quantity and the traffic safety in the first place are all examples of the latter. Although both mentioned technologies are intertwined and complement each other and are of equal importance, slightly more will be told about the ICT significance, particularly about the integral information systems for a complete and efficient ITS.

.

2.1. Transportation as technology component of ITS

According to the definition, transportation entails a range of activities related to transportation of people, goods, but also information from one physical position to another. Transportation consists of transport infrastructure, vehicles and associated activities when materially speaking. Transportation classification is based on infrastructure and vehicles, but we should also note the fact that transportation is an economic-financial category, and it entails all the transport related

[1] Corresponding author: pogarcic@veleri.hr

activities and communications. When talking about transportation as a specialized activity, though, its realization requires transport infrastructure and total upgrade to ensure transport services. Although transportation and transport have almost the identical meaning, they aren't considered synonyms in this paper (Perallos at all, 2015).

On the other hand, a need for the ITS, as a general framework is a result of different activities. It's enough to take into account an increase in vehicle numbers to meet individual and group needs, general urbanization increase and changes it causes regarding the population density. There has also been recorded an increased impact of transportation on the environment through the air pollution and an increased fuel consumption, while decreased transport infrastructure efficiency results with traffic jams intensity increase, which exacerbates the quality of transport communication. (Horberry&Regan, 2014) The latter lead to utilisation of Information and communications technology (ICT) and the potential it provides in order to eliminate shortcomings and improve the quality of traffic. ICT is very practical and convenient since it enables "what if" type of computer simulation, "just in time" type of traffic control and a possibility to create and manage communication networks. Intelligent transportation systems (ITS) can be defined as a holistic, control and the ICT (cyber) upgrade of classical traffic and transport system which has significantly better performance, traffic flow, more efficient transport of passengers and goods, enhanced traffic security, comfort and safety of passengers, decreased environmental impact, etc. (Richard at all, 2002) The ITS signifies a new critical term which is changing the approach and the development trend of the Transportation Science and Technology of people and goods transportation, by efficiently eliminating rising problems of traffic congestions and environmental pollution, so as an increase of transportation efficiency and safety and protection of people and goods in traffic. In that way, an intelligent road represents a cyber and the ICT upgrade of classical roads which main differences are beside basic physical functions the following ones: better informing for drivers, better traffic management, safety apps, etc. (Williams, 2008) ITS is a system that provides services and pieces of information to the users via distributed information system while using the user- friendly interface for a user or a moving object, for both private and public sectors. ITS system has to be convergent and open-source, by providing, on the one hand, application of various technologies based on interactive and multimedia characteristics, and on the other hand, guaranteeing integrity action across a wide geographical area, from micro-locations to macro- locations. The main purpose of the intelligent transportation system implementation are to: raise the quality of traffic and transportation, enhance experiences of drivers and passengers, improve travel related procedures, exchange of goods and services and increase the overall traffic and information transparency. The primary goal of the ITS is, therefore, a system integration which will improve travels and transportation through more efficient and safer movement of people, goods and information together with greater mobility and fuel efficiency and less environmental pollution.

For the purposes of the paper it is necessary to emphasize the goals, which define more precisely the ITS, and those are the following ones: the increasing of the whole transportation system, the increasing of the mobility of people and goods, prevention and decrease of accidents and damages caused by transport, energy consumption decrease and long-term controlled environmental protection. The base of the ITS consists of system monitoring and ICT solutions as a part of the network infrastructure, vehicles, control centres and various ICT equipment. However, it is necessary to acquire a work definition of the ITS for purposes of singular viewpoints in this paper. The following definition is acceptable for those purposes: "Intelligent transportation systems (ITS) are advanced applications which, without embodying intelligence as such, aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and "smarter" use of transport networks." (DIRECTIVE 2010/40/EU.....) Thereby it is necessary to emphasise the importance of the ITS as a holistic, control and information and technology upgrade of the classical traffic and transportation system.

.

2.2. Holism and the ITS standardization

Although the European and the American viewpoints about the ITS integration are slightly different, the European perspective is considered to be the leading one when it comes to the domain of organised activities of the traffic and transportation. However, the implementation of the ISO standardisation has helped to achieve the full significance (Ortizar&Willumsen, 2011) (ISO/TC 204).

2.3. EU and the national frameworks of the ITS

Although ITS may refer to all modes of transport, EU Directive 2010/40/EU (7 July 2010) defines ITS as systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport. In accordance with above-mentioned at the national level, the Republic of Croatia issued the proposal of the National Program for the Development and the Deployment of Intelligent Transport Systems in the road transportation for the 2014-2018 period. Five national priority areas are planned to be covered by the National Program for the Development and the Introduction of the ITS in the road transportation for the 2014-2018 period as shown on Figure 1.

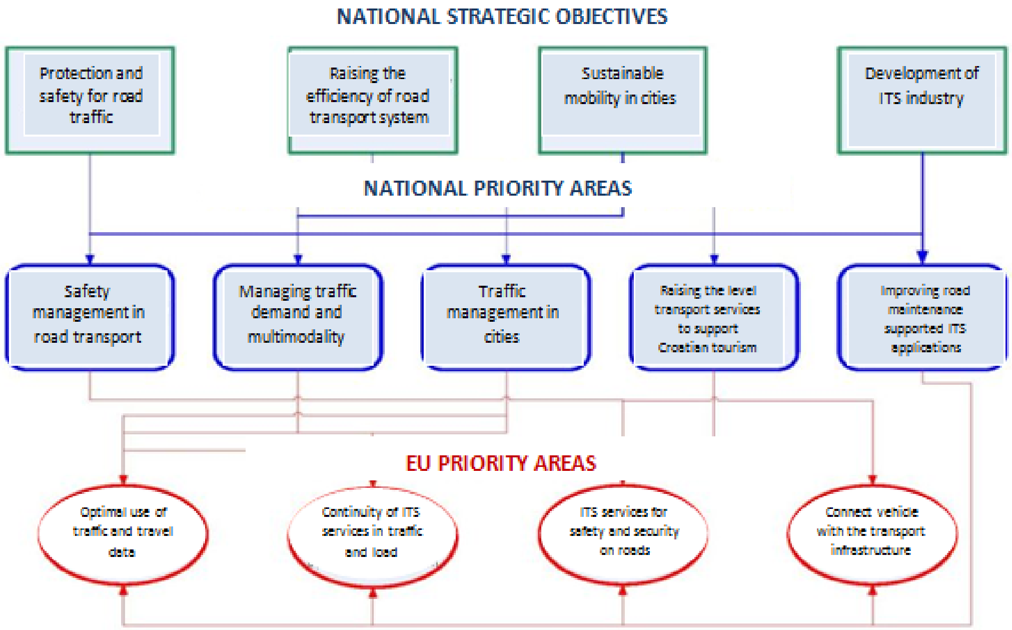


Fig. 1.
National Strategic Objectives
Source:http://www.mppi.hr/UserDocsImages/Nacrt%20Prijedloga%20Nacionalnog%20programa%20za%20uvodenje %20i%20razvoj%20ITS.PDF

The areas mentioned above are of national interest, and they emerged from the Action Plan for the Deployment of Intelligent Transport Systems in Europe, COM(2008) 886. It is the document which initiated a stronger focused deployment of the ITS in the road transportation in the field of the EU. The Action Plan is a result of experiences acquired in studies within ERTAC and ERTICO-ITS technological platforms and a need for a framework structure which would enable to harmonize the ITS deployment in the EU's road transportation. The Action Plan followed the public hearings and discussions between the key stakeholders and it is shown on Figure 2.

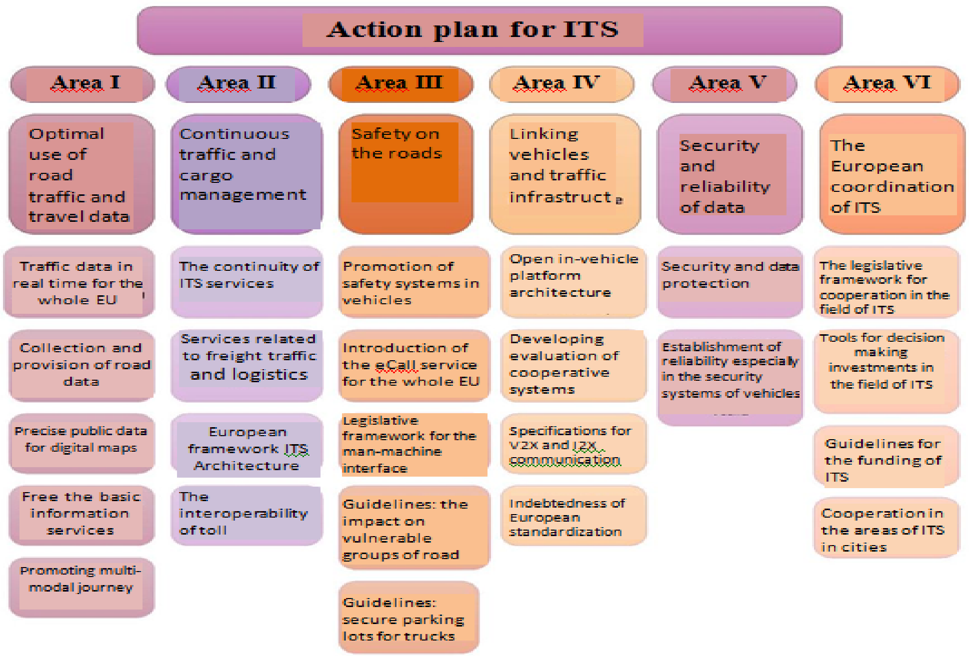


Fig. 2.
Action Plan for ITS
Source: DIRECTIVE 2010/40/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 July 2010. eur-lex.europa.eu

2.4. Informational frameworks for the ITS- holistic approach problem

According to the content of the Action Plan and above mentioned ITS definition, it is of particular importance to insist on the holistic approach and integral solutions and the fundamental architecture of the ITS respectively. The simple reason why it is not possible to separate those two essential technologies of the ITS is the following one: although both technologies have different realisation, they belong to the same activities. To be more precise, the transportation wouldn't exist as an activity without a high-quality information support, whereas the information system wouldn't exist for its sake. When scrutinising the Action Plan and the list containing 32 essential services, it is possible to note the importance of the prompt and valid informing. Also, it is possible to envisage dimensions of such a system. Considering the requirements which this system meets, it is understandable that such a system has to be robust, dynamic and flexible both in structure and architecture. Frameworks in this paper are neither sufficient for a complete and detailed elaboration of nor technological, neither informatics component. (See more)(DIRECTIVE 2010/40/EU), (Sladkowski&Pamula, 2015).

The purpose of this paper is to emphasise the importance of the integral solution and especially the importance of informatics component organisation. It is, therefore, according to author's humble opinion, enough to hypothesise the working hypothesis which will, by using just one ITS aspect, clearly indicate the advantages of establishing a high-quality information system realisation. Although all the elements of the information system are equally important, its quality is mostly determined by both quality of its database, and data processing. That's the core issue since the prompt and valid informing of the users will depend on it. If we perceive it as a problem, it is clear that even the users will have to be a competent and capable of using the services of a system like ITS. It indirectly means that a user should be computer literate. It is clear that a high-quality database has to be organised and maintained by trained staff and professionals. However, it is also clear that the system with such a database enables the access to the interactive database, so as a possibility to update certain content quickly.

This point might sound a little bit too exaggerated or too ambitious from this point. Such impression can be obtained just at the first sight. Having considered some other systems with a similar way of functioning, indicates that such a quality can be implemented by a complete and active involvement of all stakeholders of such a system. To illustrate this point, personal, user and individual involvement in the usage of telecommunications, like mobile phones or even better Internet Banking and Mobile Banking systems, are enough to consider. The biggest issue, though, is to determine which and what kind of information will be needed and who, where, when and how they will be collected. It is clear that the information has to meet certain quality criteria. The implemented and planned activities related to standardisation of certain processes and events have already been mentioned. Since the established standardisation system on the informatics field already exists, a formation of firmly defined, but multiple sources information, shouldn't be a big problem. It's important to emphasise a chance for the user of such system to have multiple roles when it comes to different services requests within the ITS and other various requests for information.

2.5. Hypothetical case of the ITS utilisation

The modified hypothetical author's case is employed to illustrate the necessary services and data within the high-quality ITS. Suppose hypothetically: “Owner of an expensive automobile equipped with equally expensive devices that include GPS is a male person in his thirties. During a longer journey he has been using services of GIS system that is implemented into latest GPS device. During the journey he followed instructions given by GPS device, so he faced situation and circumstances on highway which mostly haven’t correspond to information provided by GPS device. In that specific situation the automobile has been completely ruined, while the owner has been experienced severe body contusions which haven’t threatened his life, but could contribute to consequences of minor body disability.” (Pogarcic, et al., 2012)

Although the authors put emphasis on GPS and GIS, it is clear that those are just components or elements which are a part of the ITS in full. To this possible case, it is evident that a lack of the right information in the first place is a cause of all the consequences emerging from the above mentioned hypothetical case. When observing the image No. 2 of the Action Plan more carefully, it is possible to notice that most of the areas stress the importance of the data. In that way, it is possible to notice not just a vertical correlation between different subareas, but also the importance of the horizontal correlation and area and subareas connectedness. Although the mentioned hypothetical case puts emphasis on the lack of a high-quality information, from completely one part of the information system, in the following deliberation the emphasis is beside information, to the user of those pieces of information, and to all potential users involved in similar events respectively. However, even when the situation is procedurally clear, there is a possibility that the participators won't understand the same term. The explanations are given to illustrate of the mentioned use case, but from the rights and obligations aspect emanating from the requirement of insurance of agents and persons in traffic. The damage is a term and legal institute defined by the Law of Obligations(in Republic of Croatia) (N.N.). (http://narodne-novine.nn.hr/default.aspx) The Law of Obligations unambiguously defines the damage types specifically as the violation of traffic participants personal rights. The traffic accident indemnity is prescribed by the Law of Obligations as both, *lex generalis* and *lex specialis*. According to the Law of Obligations, the victim of a traffic accident has to claim on the insurance company of the person who caused an accident. Together with the mentioned claim, the victim of a traffic accident submits a police report, medical record and other relevant documentation which proves the extent

of damage and expenses occurred before submitting the claim in order to prove and justify the required amount of money for the reimbursement.
The reason why the victim should claim on the insurance company, and not on the person who caused an accident personally, is the fact that doing so, strengthens the economic and legal security of the victim, and it also facilitates the obtaining of the required amount of money as reimbursement from the insurance company. Among all the required documentation in case of a traffic accident, a police report is of particular importance. It consists of all relevant data on a traffic accident such as: data on a police officer who writes a police report, data on the police department the police officers belong to, general and personal data on a victim and a person who caused a traffic accident that undoubtedly identifies them (full name, date of birth, residence address, personal identification number, national identification number and driver's license number). After obtaining personal data, the Report of Accident Occurrence is filled in with the following data (related to the description of the place where a traffic accident occurred): time of arrival of police officers at an accident, time of an accident, types of a car of the victim and the person who caused an accident, car brand and vehicle identification number, car parts damaged in an accident, position of the vehicle on a road, skid marks, etc. Then the following data is entered: weather and visibility conditions (whether the accident occurred at night or during the day), whether the road was slippery or not and whether water spots, oil stains or some obstacles were spotted on a road. Additional technical data include: whether an accident occurred on the straight or curvy part of the road, length and sharpness of a band and whether traffic signs were installed and were easily visible. Data about the concentration of alcohol and drugs, which can impair motor coordination and the ability to assess the weather conditions and other obstacles on the road, are recorded as well. Therefore, the Report of Accident Occurrence is a relevant documentation which can prove the accident occurrence and its authenticity. If an insurance company didn't comply with the requirement of a victim or it considered it unfounded, the victim would have a right to appeal to the insurance company. By filling a complaint, the victim initiates a civil action against the insurance company. The victim can arraign the mentioned claim, according to the Law on Civil Procedure, on the court of competent jurisdiction of the place where the accident occurred, residence address of the person who caused an accident or residence address of the victim. However, in a case of any dispute, there is a chance of presenting expert witness opinion testimony (Traffic Accident Expert Witnesses, Medical Expert Witness). After implementation of all evidence, the Court concludes the main discussion and renders a judgment which can adopt the plaintiff's claim or reject it as unfounded.

3. Summary as a conclusion

It is evident that a traffic accident, as a particular event in the security of the ITS, should be well elaborated, and all the pieces of information should be unambiguously defined. The previously mentioned fictive use case emphasized that the GIS as a system, police as an institution, judiciary as an institution, individual traffic participants, despite the type of traffic, share the same set of information and data set. However, every single stakeholder has own needs and own approach on that set. It doesn't exclude the need to define the database and that kind of information system- ICT component of the ITS which would be made according to the rules of positive trends in information systems development. The system should also have a certain hierarchical structure since it should meet requirements at the local, national and international levels. All in order to ensure integrated traffic security and quality. The recent information technologies and the information system structure- cloud computing and object- oriented approach from a technological point of view are more than enough for a realisation of the system with a high-quality database. The aim of this paper was to emphasize a need for such a realization and to point out the possibilities and advantages of the system. Most of the previous discussions were of course, just colloquial since the problems go beyond the limits allowed by a framework. It is clear that the authors will strive, in the following papers and deliberations, to insist on solutions which need to offer both holistic approach and solutions.

References

DIRECTIVE 2010/40/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 July 2010. eur-lex.europa.eu on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.

Horberry, T.; Regan, M.A. 2014. *Driver Acceptance of New Technology: Theory, Measurement and Optimisation (Human Factors in Road and Rail Transport),* CRC Press; ISBN-10: 1409439844, ISBN-13: 978-1409439844.

ISO/TC 204 Intelligent transport systems. Available from Internet: <http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=54706>.

Ortizar, J.; Luis, G.; Willumsen, L.G. 2011. *Modelling Transport*, Wiley, ISBN-10: 0470760397, ISBN-13: 978-0470760390.

Perallos, A. et al. 2015. *Intelligent Transport Systems: Technologies and Applications,* Wiley, ISBN-10: 1118894782, ISBN-13: 978-1118894781.

Pogarčić, I.; Pogarčić, M.; Pogarčić, M. 2012. The requirement for the legal regulation of commercial relations in cloud computing, Security Enhanced Applications for Information Systems, Christos Kalloniatis (ed.), Athena: University of the Aegean, Greece, 161-182.

Richard, T.T. et al. 2002. *Road Ecology: Science and Solutions, Island Press*, ISBN-10: 1559639334, ISBN-13: 978-1559639330.

Sladkowski, A.; Pamula, W.; 2015. *Intelligent Transportation Systems - Problems and Perspectives (Studies in Systems, Decision and Control)*, Springer, ISBN-10: 3319191497, ISBN-13: 978-3319191492.

Williams, B.; 2008. Intelligent Transport Systems Standards, Artech House Publishers, ISBN-10: 1596934387, ISBN-13: 978-1596934382.

Zakon o obveznim odnosima (Obligations Act) (<http://narodne-novine.nn.hr/default.aspx>), *Narodne novine br.: 35,17.03.2005*.

ANALYSIS OF DRIVER REACTION TIME USING THE ACQUISITION OF BIOSIGNALS

Kateřina Bucsuházy[1], Veronika Svozilová[2], Olga Vallová[3], Marek Semela[4], Jiří Sekora[5], Michal Belák[6], Pavel Maxera[7], Robert Kledus[8]

[1,4,6,7,8] *Institute of Forensic Engineering, Brno University of Technology, Purkyňova 464/118, 61200 Brno, Czech Republic*

[2, 5] *Department of Biomedical Engineering, Brno University of Technology, Technická 12, 61200 Brno, Czech republic*

[3]*CEITEC – Central European Institute of Technology, Brno University of Technology, Purkyňova 123, 61200 Brno, Czech Republic*

Abstract: Nowadays determination of driver's reaction time has become a main characteristic in the field of traffic accidents. Duration of driver reaction time is the main characteristic of driver himself and his behavior in the phase right before collision. This article is a part of an ongoing research project concerning innovative technique of biosignals' acquisition. The goal of this work is to distinguish and analyze driver reaction time and individual components of this reaction time (especially time needed for the decision and muscle response) and interaction between driver and vehicle in detail. For this purpose a combination of conventional methods, i.e. eye-tracking, and methods used for biosignals' acquisition, i.e. electromyography, has been proposed. Eye-tracking method is used to measure a view direction or eye movements relative to a head. This paper describes a use of the video-based eye-tracker combining a video images and a pupil reflection exploiting an infrared light. The driver's neuromuscular dynamic is important aspect of the interaction of driver and vehicle. Measurements of voltage during muscle activation (electromyography, EMG) are used to identify the muscles involved in interaction of driver and brake pedal. The main focus of this article is to determine all components of driver's reaction time involving experiments in real traffic. Additional evaluation is used as a basis for analyses of driver's behavior and reaction time in each respective situation. Results of this research could be beneficial for detailed investigation of the effects that have impact on the extension of reaction time which can lead to accidents.

Keywords: reaction time, eye-tracking, electromyography, driver, muscle response.

1. Introduction

Nowadays, trend of accident analysis researches has been tended to reduce the number of road traffic accident in every day driving conditions. The main cause of road accident is a human factor i.e. driver´s behavior. Police accident data confirmed that more than 90 percent of road accidents have been caused by human errors. It is important to know the driver behavior considering a road accident analysis and a road safety. The main personal characteristic is human reaction time (RT) as a time taken to complete a task.

In recent years, a work focused on the driver behavior has used eye-tracking methods. Eye-tracking methods have been used to measure a view direction or an eye movements relative to the head and have allowed monitoring, detecting and evaluating of visual sequences of drivers (e.g. Pfleger and Jechlinger, 2010; Pfleger and Hohenbüchler, 2011; Pfleger 2013; Kledus et al., 2013). Recently, eye-tracking methods have begun to be combined with an electrical potential measurement because of specification and more detailed analysis of reaction time. In a real traffic, an electrical potential measurements (electroencephalogram - EEG, EMG – elektromyogram, electrocardiogram – EKG and a heart rate variability, etc) are used rarely, they are used especially for a fatigue detection (Eoh et al., 2005; Katsis et al., 2004). These methods are used for verifying or calibrating of alertness systems frequently, typically EEG. Some recent studies have used combination of vehicle control information (steering, braking) and video capture for monitoring emotion with various physiological measures to assess the driver performance (Leenman et al., 2005; Michalski et al., 2004). In study (Mcgehee et al., 2010) combination of vehicle control information (steering wheel pressure) and video capture for monitoring facial state change has used to analyze non alerted driver response during a pre-crash.

In (Green, 2000) a literature review pointed out to a fact that the generalization of central tendency parameters (means or medians) taken from various studies did not take into account the important variance of drivers' RTs. He also criticized observed RTs values' distortion caused by using not strict unexpected situations especially in simulator studies. It led to bias and arbitrary estimate and shorter observed RTs. Therefore Green has suggested to that there should be more emphasis on the analysis and production of real data including driver reactions as a function of situational variables. Based on Green's suggestion the aim of this study was to analyze driver behavior in real traffic.

In general RT consists of three components – visual reaction time, psychical reaction time and physical reaction time. Visual reaction time is a time required to the object noticing (TON) and the visual fixation in the sharp vision area (TF). Psychical reaction time has been defined as a time between the visual fixation and the movement reaction time, it is time needed to object recognition by the central nervous system (CNS) and time needed to muscle activation. Physical or movement reaction time is a period of time in which the limb is moved from accelerator pedal (accelerator release time TA) to the brake pedal (TB). The goal of this work was to analyze and determine a time needed to object recognition in the CNS. In fact, it means the time needed to a decision about reaction and style of respond (TD = Time needed to decision). Use of electromyography allowed to determine the moment of muscle activation (TEMG). For the purposes of this study the muscle activity of the right lower limb was recorded by surface electromyography electrode

[1] Corresponding author: katerina.bucsuhazy@usi.vutbr.cz

system. Many studies analyzed the movement time (e.g. Pierson et al., 1959; Spirduso, 1975), but in this study the whole duration between the moment of muscle activation and activation of brake pedal (muscle response time = MRT) were investigated. Compared with the parameter of the movement time this parameter provided a more accurate picture of muscle work.

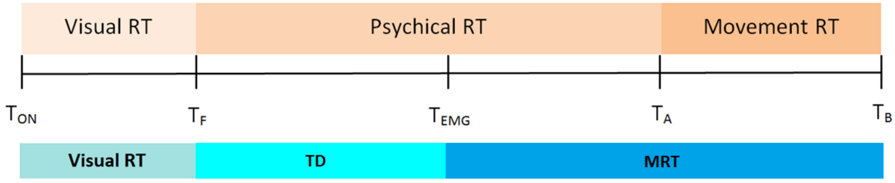


Fig. 1.
Driver reaction time

Primarily, this study was focused on the analysis of muscle activity and differences occurring during muscle work in different types of reactions in real traffic. Main conclusion in (Green, 2000) was that driver expectations are the most important variable affecting RTs. During the experiment in real traffic conditions three types of stimuli were included, unexpected stimulus (US), expected stimulus (ES) and critical braking as the reaction to the abrupt visual stimulus (CB).
In case of critical braking we tried to find out the shortest reaction time. Visual RT was eliminated by using the assumption published in (Bradáč, 1999), where it stated that if the angle of target is zero degrees, visual reaction time is null. Drivers were instructed before the beginning of the experiment on the short predefined route about the stimuli type, the required reaction, therefore time needed to the decision was reduced and due to this fact MRT was tended to minimize its duration.
Because of safety, use of dangerous and truly unexpected stimulus is not possible. As a compromise between the safety and the most unexpected stimulus a ball thrown in front of the driver at the one-way street was selected. Expected stimuli were objects found in real traffic (semaphore, pedestrian crossing street, STOP signs, etc.) commonly.
To ensure the comparability of responses, drivers drove on the same route. Four pedestrians stood at predetermined crosswalks. Many studies (Green, 2000; Pierson et al., 1959; Spirduso, 1975) confirmed the impact of age and gender on drivers' reaction time. This study was carried out with 12 men between 25 – 35 years.
In future, this research could be beneficial for driver behavior analysis of selected groups with some specific injuries or illnesses (e.g. Parkinson disease). Results are contributing not only to improve traffic safety, but they can be used in the road accidents' analysis. Future research should be beneficial for quantification of reaction time among selected groups.

2. Methods

The aim of this case study was to analyze driver reaction time in real traffic in detail. For this purpose, combination of eye-tracking method and measuring electrical activity of muscles was developed. To synchronize these two methods signals from both devices were marked at the same time moment by using the own device. The infrared LED was activated, the start time corresponded to the video frame in which the first LED blinking could be observed and to signal sample in which the level of the sensed signal from tibialis anterior was null.

2.1. Eye-tracking

Eye-tracker is a device that is used to measure eye movements. Eye-tracking method is used to measure motion of an eye relative to a head. The purpose of the eye movements is to fixate objects in the field of a view, in the area of sharp vision (foveal region). There are two main methods to detect the eye movements. In this research mobile eye-tracking Pupil was used.
Pupil is comprised by a light-weight headset with high-resolution scene and eye camera and can provide an average gaze estimation accuracy of 0.6 degree of visual angle. The video-based eye-tracker combinines a video images and a pupil reflection exploiting an infrared light [attachement, Fig. 1, Tab. 1]. An infrared light is shone into the eye and then it is reflected from the lens and sensed by a video camera (Kassner et al., 2014).

2.2. EMG

Generally for recording and evaluating the electrical activity produced by skeletal muscles the technique called electromyography (EMG) has been used (Merletti, 2004) and this method was utilized even in this project. The electrical activity of seven muscles of the lower right limb were acquired by using wireless surface and finewire EMG systems Cometa. In [attachement, Tab. 2] technical specifications of Cometa device are introduced. EMG system Cometa consists of two main parts. First part is a set of 16 electrodes which can be placed on the human body and this set serves to biosignal acquisition.

In this case seven electrodes were placed on the lower right limb Fig. 2: musculus iliopsoas as a primary mover of hip flexion; musculus gluteus maximus as a primary mover of hip extension; and musculus gracilis as a primary adductor of the hip joint. Postural changes of the knee joint were detected by recording from musculus quadriceps femoris (precisely rectus femoris) as a main mover of knee extension; and musculus semitendinosus as one of knee flexors. Movements of the ankle joint were monitored by measuring of electrical activity of musculus triceps surae as a primary mover of plantar flexion; musculus tibialis anterior as a primary mover of dorsiflexion and foot inversion; musculus peroneus longus as a main mover of foot eversion as well as foot abduction. Placement of electrodes was carried out in accordance with the SENIAM research group recommendations (Hermens et al., 1999).
First step of biosignal’s acquisition is recording signals into the external memory attached to the sensing electrode. Second step of biosignal’s acquisition is data transfer from external memory to the PC software where these data are processed and evaluated. In the [attachement, Fig. 2] the sensing electrode (number 1), which is placed directly on the one skeletal muscle, and the external memory (number 2) are introduced.
Second part of EMG system Cometa is a software for data processing. Acquired data can be processed offline and also data can be monitored in online mode. EMG data should be limited by 10-20 Hz from the bottom and 450-500 Hz from the top, therefore the software provides the basic data pre-processing by using 10-500 Hz band-pass filter.

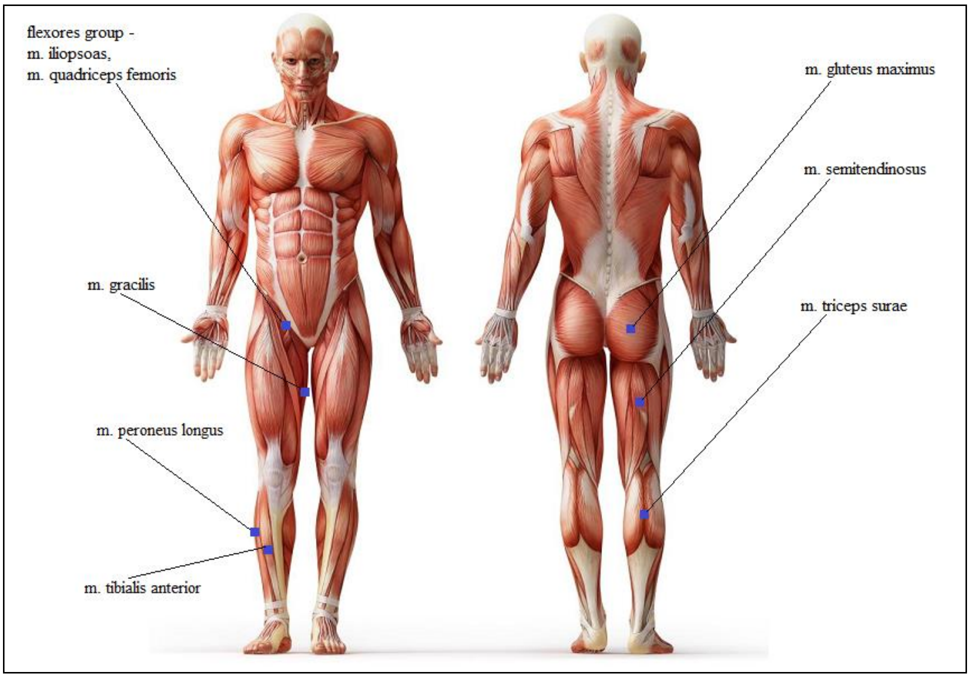


Fig. 2.
Placement of electrodes-lower right limb
Source: Perry (2011)

3. Results

In the course of experiment every driver was exposed to two different types of braking reaction. First reaction was represented by gradual braking (e.g. expected pedestrian, red light on semaphore) and second stimulus was represented by swift braking (e.g. unexpected object, critical braking).
Analysis of visual component of reaction time should be made by eye-tracking technique. As mentioned in (Kledus et al., 2013), limitation of eye-tracking method and determination of visual reaction time is due to a situation which do not require significant changes of driver’s sight angle. In this work use of expected stimuli did not require the significant change of this angle, therefore if object was in driver field of view, visual reaction time was minimalized or null. Because of this reason visual reaction time has not been analyzed separately. In some cases visual reaction time could be a part of TD or it could overlap with TD. In the case of pedestrians, drivers sometimes reacted not to pedestrian but their reactions started at the moment they noticed the zebra crossing. In this case time needed to drivers’ decision started when they noticed the zebra crossing not the pedestrians.
TD has been determined as a time between visual fixation of object and start of tibialis anterior work. Tibialis anterior muscle is considered the muscle that firstly reacts in emergency situation (Seto et al., 2004; D´Addario et al., 2014; Gao, 2015). In case of critical braking, TD was minimalized by warning on visual stimuli during the predetermined route. Box plot in Fig. 3 of expected objects shows more significant span than other box plots. Maximum reflected the situations when object was totally expected and drivers had enough time to react, they analyzed situation and decided to react (or not to react). Low values reflected situations when object was on the border of predictability.
MRT time has been determined as a time between start of tibialis anterior work and activation of brake pedal. Indeed interesting results were obtained by a comparison of box plots for critical braking and unexpected stimuli (Fig. 3). Ball

thrown in front of driver in one-way street near children's playground was more stressful, so median of MRT time was smaller than median of critical braking. This fact was not able to be observed in TD, because in case of critical braking drivers knew the type of reaction (they were instructed to stop depending on the appearance of visual stimulus), therefore they did not need such a long time for a decision.

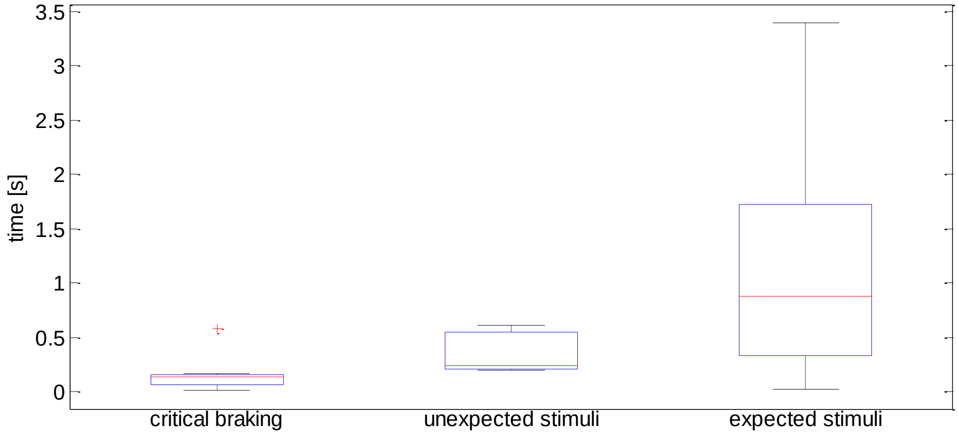


Fig. 3.
Box – plot of TD
(red line: median, blue box: 25% - 75%, black lines: 5 – 95%, red cross: outliners)

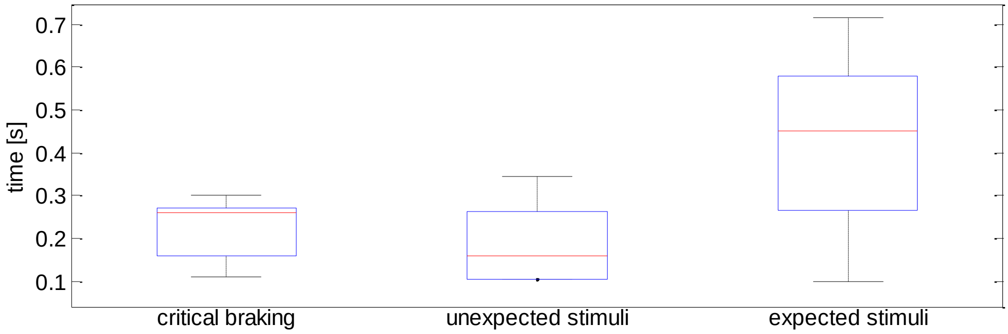


Fig. 4.
Box – plot of MRT
(red line: median, blue box: 25% - 75%, black lines: 5 – 95%, red cross: outliners)

In an effort to leave the accelerator, functional chain of movements started by triple flexion of entire lower limb, including flexion of the hip joint, flexion of the knee joint and dorsal flexion of the talocrural joint (proper ankle joint). It was followed by internal shift of entire limb above the brake pedal accompanied by hip adduction. Closing stage was composed of triple extension of the lower limb, including hip extension, knee extension and plantar flexion of the talocrural joint. Plantar and dorsal flexions were connected with eversion or inversion according to the type of kinetic chain.

Commonly kinetic chains are divided into "open" and "closed" chain. Basically, during closed kinetic chain (CKC) the distal segments of the chain are fixed and proximal segments are moving. During open kinetic chain (OKC) the situation is inverse, when proximal parts are fixed and distal segments are moving (Wilk et al., 1996; Chang et al., 2014). In the open kinetic chain dorsiflexion is connected with the eversion, and abduction; and plantar flexion with inversion, and adduction. In the closed kinetic chain plantar flexion, is accompanied by abduction and eversion; while dorsiflexion is accompanied by inversion, and adduction (Rockar, 1995).

Results obtained by electromyography of the right lower limb shown us different muscle activity during various type of braking intention. Swift braking, as the reaction on the unexpected stimulus, induced isometric muscle contraction (visible on EMG as a rapid motor unit recruitment of all recorded muscle groups). By contrast, within gradual braking, as a reaction on the expected stimulus, sequential motor unit recruitment was noticeable. This muscle timing was typical for muscles of the ankle joint and foot, concretely, always after the expected stimulus the constant sequence came in the order given: m. tibialis anterior, m. peroneus longus, and m. triceps surae. It followed that braking reaction started by dorsiflexion with foot inversion induced by musculus tibialis anterior. It was compensated fast by the activity of antagonist muscle represented by musculus peroneus, which provoked foot eversion, because the main function of the peroneal muscles was to control the amount of the foot inversion and reflexively protect the ankle joint (Grüneberg et al., 2003; Ashton-Miller et al., 1996). The last step of braking was a step on brake pedal with strong plantar flexion induced by concentric contraction of the musculus triceps surae.

By observation of the mutual activity of the musculus peroneus longus and musculus tibialis anterior we are able to assume the functional stability of the ankle joint. Insufficient activity of peroneal muscles endangers stability of the ankle joint and does not allow distal segments to keep fixed position and to provide sufficient support for entire functional chain of the lower limb. This could have significant impact on stability of main body.

The investigated movement was bounded by the onset of tibialis anterior and the rising edge of footswitch signal (footswitch electrode was placed on the right sole). This bounded signal was analyzed in time and frequency domain. In the case of time domain analysis the time of the investigated movement was determined and in the case of frequency analysis the dominant and the median frequency was investigated.

In Fig. 5 muscles' activation during the critical braking in time domain is introduced. As mentioned above, the activation of three main muscles during the critical braking should be performed almost simultaneously and this fact can be seen in the red sector. From these signal's sets for all types of stimulus MRT was determined and compared with published results (Bradáč, 1999). In frequency domain the dominant (MNF) and the median frequency (MDF) of investigated time for all types of stimuli was determined by using periodogram method (Merletti, 2016). Signals' sections corresponding to the investigated times were turned into spectral domain and frequency representation was estimated. Illustration of one result from periodogram is introduced in [attachement, Fig. 3]. From this result the dominant and median frequency was found out.

Analysis in frequency domain was used to compare the signals from all types of stimuli. It was investigated whether the frequency representation of the investigated times changed depending on the type of stimulus by estimating the dominant and the median frequency. In Fig. 5 box-plots of MNF and MDF are introduced.

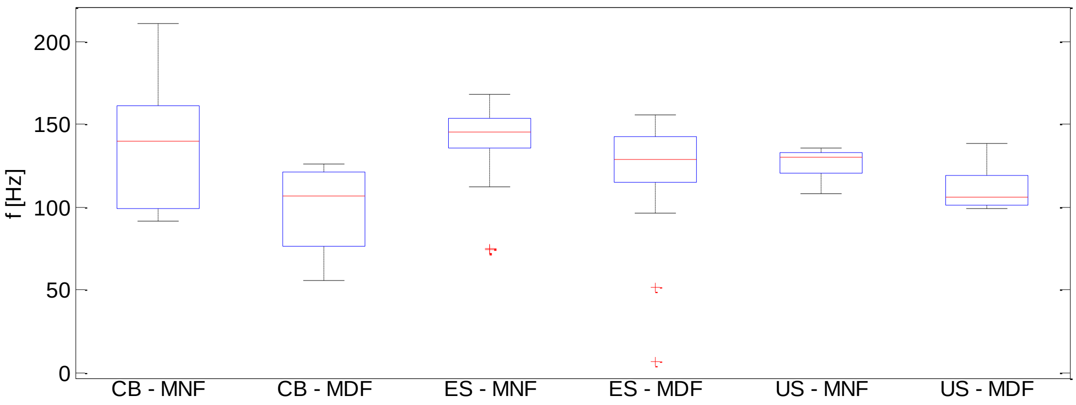


Fig. 5.
Box-plot of dominant (MNF) and median (MDF) frequencies

Finally, box plot in Fig. 6 provided the results of TD and MRT in sum. RTs for unexpected stimuli were in accordance of published results (Bradáč, 1999) and accident analysis used range, critical braking provided the lower border for RTs. Preview on the reaction time in real traffic provided results of RTs on the expected stimuli.

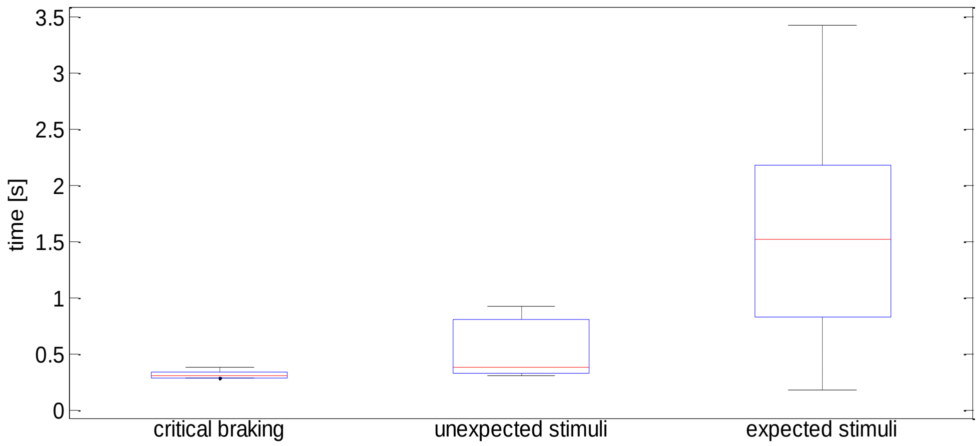


Fig. 6.
Box-plot of MRT plus TD
(red line: median, blue box: 25% - 75%, black lines: 5 – 95%, red cross: outliners)

4. Discussion

The biosignals' acquisition can be viewed as a new approach how to analyze driver's manners in real traffic. For the acquisition of muscles' signals the set of electrodes placed on the lower limb has been designed. Duration of MRT and TD of the driver reaction can be founded by combination of electromyography signal acquisition and use of eye-tracking. Limitations of used technique (eyetracking) did not allow the analysis of visual reaction time in detail.
Critical braking results are characterized by the shortest RTs. In accident analysis the shortest values as this may not be used. Minimization of TD obtained by warning on visual stimuli on predetermined route, visual reaction time were eliminated because of zero angle of visual stimuli. Apparently the MRT was shorter in case of the unexpected stimuli unlike in case of critical braking. Prerequisite for this result is fact that the more stressful stimulus causes a higher risk of danger than the critical braking caused by the artificial visual stimulus. TD for the unexpected stimuli was estimated in conformity with published results (Bradáč, 1999). Results of RT analysis of the expected stimuli were characterized by considerable variation. It was caused by a large number of stimuli occurring in real traffic. Low values reflected situations when drivers did not expect the specified object. High values reflected the defensive drive, drivers did not react straight to the stimulus but to the upcoming situation in real traffic (e.g. driver reacted to the zebra crossing – upcoming situation, not to the pedestrian - stimulus).
Conclusions mentioned above were confirmed by statistical analysis. The analysis of variance (ANOVA) indicated significant differences among TD plus MRT of the expected stimuli and all of investigated parameters excepting TD of the expected stimuli. TD of the expected stimuli varied significantly from MRT of the expected stimuli. Duration of TD is dependent to the driver decision unlike MRT. Predictability of stimulus provided to drivers a large space for decision. If they decided to react, muscle response was similar in all types of the expected stimuli (therefore the variance of MRT was not so significant unlike TD). ANOVA was performed on the level of significance $p = 0.05$.
Obtained results revealed a fact that initial part of braking was first of all represented by dorsal flexion with inversion, which is typical for closed kinetic chain. After that, eversion with plantar flexion followed as is typical for closed kinetic chain too. Which means that direction of muscle contraction was from proximal insertion to distal, and distal segments provided functional support for moving proximal segments. The reason for this functional chaining could be impact of inertia.
It was found out that from seven monitored muscles of the lower right limb three skeletal muscles were involved in the investigated movement the most, m. tibialis anterior, m. peroneus longus and m. triceps surae respectively. Furthermore it was found out that in the case of expected stimulus these three muscles were activated gradually unlike the case of unexpected stimulus and critical braking where these three muscles were activated almost simultaneously.
The assumption was whether the value of the dominant frequency corresponded to the type of stimulus. In the context of our project, analysis in frequency domain should help to investigate muscles' activities during expected and unexpected stimuli and during the critical braking. It was found out that values of MNF and MDF for each type of stimulus were estimated in similar range. It means that level of muscle activity was comparable among all types of stimulus. Depending on the stimulus type the span of MNF and MDF varied markedly. MNF and MDF values (as well as MRT) of critical braking depended on the physical condition of participants the most.
Obtained results were analyzed not only in terms of duration but also in terms of physiology and function mechanism. This detailed analysis offers a wide range of applications for the analysis of reaction times of specific groups of drivers with diseases of the neuromuscular system. Contribution of this case study may be seen in use of the combination of conventional methods, i.e. eyetracking, and methods using biosignals' acquisition, i.e. electromyography, for analysis of reaction time not only for simulated conditions but also for stimulus commonly encountered in real traffic.

Acknowledgements

This research was drafted within the scope of the Specific university projects named "Reaction time analysis using eyetracking and biosignal aqusition" (No. ÚSI-J-16-3549) and "Analysis of driver's behaviour when passing through accident pedestrian crossings in the city of Brno using the eye tracking method" (No. ÚSI-J-16-3713) performed by the Brno University of Technology, grantor: Ministry of Education, Youth and Sports. This research was also carried out under the project CEITEC 2020 (LQ1601) with financial support from the Ministry of Education, Youth and Sports under the National Sustainability Programme II; and under the project FEKT/STI-J-16-3627 "Objektivization of talus bone position within Foot Posture Index assessment using the optical sensor Kinect" financed from internal grant system BUT.

References

Ashton-Miller, J.A. et al. 1996. What best protects the inverted weightbearing ankle against further inversion? Evertor muscle strength compares favorably with shoe height, athletic tape, and three orthoses, *The American journal of sports medicine,* 24(6)*:* 800-809.

Bradáč, A. 1999. *Soudní inženýrství.* Akademické nakladatelství CERN, Brno. 725 p. ISBN 80-7204-057-X.

Chang, W.D. et al. 2014. Effects of open and closed kinetic chains of sling exercise therapy on the muscle activity of the vastus medialis oblique and vastus lateralis, *Journal of physical therapy science,* 26(9)*:* 1363-1366.

D'Addario, P.M.; Donmez, B.; Ising, K.W. 2014. EMG provides an earlier glimpse into the effects of cognitive distraction on brake motor response. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 2200-2204.
Eoh, H.J.; Min, K.Ch.; Seong-Han, K. 2005. Electroencephalographic study of drowsiness in simulated driving with sleep deprivation, *International Journal of Industrial Ergonomics*, 307-320.
Gao, Z. et al. 2015. Experimental study of young male drivers' responses to vehicle collision using EMG of lower extremity, *Bio-medical Materials and Engineering*, 26(1): 563-573.
Green, M. 2000. How long does it take to stop? Methodological analysis of driver perception-brake times, *Transportation Human Factors*, 2: 195-216.
Grüneberg, C.; Nieuwenhuijzen, P.H.J.A.; Duysens, J. 2003. Reflex Responses in the Lower Leg following Landing Impact on an Inverting and Non-Inverting Platform, *The Journal of physiology*, 550(3): 985-993.
Hermens, H.J. et al. 1999. European recommendations for surface electromyography, *Roessingh Research and Development*, 8(2): 13-54.
Kassner, M.; Patera, W.; Bulling, A. 2014. Pupil: An Open Source Platform for Pervasive Eye Tracking and Mobile Gaze-based Interaction. In *Proceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing: Adjunct publication*, *ACM*, 1151-1160.
Katsis, C.D.; Ntouvas, N.E.; Bafas, C.G.; Fotiadis, D.I. 2004. Assessment of Muscle Fatigue during Driving using Surface EMG, *Biomedical Engineering*, (417): 112-121.
Kledus, R.; Semela, M.; Bradáč, A. 2013. Možnosti spatření chodců v extravilánu za snížené viditelnosti. In *Sborník příspěvků z odborné konference Zvýšení bezpečnosti provozu vozidel ozbrojených si*, 66-79. ISBN 978-80-904625-4-0.
Lenneman, J.; Shelly, J.; Backs, R. 2005. Deciphering psychological-physiological mappings while driving and performing a secondary memory task. In *Proceedings of the Third International Symposium on Human Factors in Driver Assessment*, *Training and Vehicle Design*.
Mcgehee, D.V.; Carsten, O.M.J. 2010. Perception and biodynamics in unalerted precrash response, *Annals of advances in automotive medicine*, 54: 315-332.
Merletti, R.; Farina, D. 2016. *Surface electromyography: physiology, engineering and applications*. John Wiley & Sons. 572 p.
Merletti, R.; Parker, P.A. 2004. *Electromyography: physiology, engineering, and non-invasive applications*. John Wiley & Sons. 495 p.
Michalski, A.; Błaszczyk, J. 2004. Physiological Measures in Road Safety Studies, *An International Journal*, (2): 49-60.
Perry, M. 2011. Full Body Workout Vs. Split Routine: Which Is Better? Available from Internet: <http://www.builtlean.com/2011/09/15/full-body-workout-vs-split-routine-which-is-better/>.
Pfleger, E. 2013. Viewing analysis of experienced vs. not experienced motorcylists and conclusions about traffic-safety. In *22nd Annual Congress FIRENZE*, 171-174.
Pfleger, E.; Hohenbüchler, H. 2011. Viewing Analyses of Drivers of Electrically Powered Bicycles and Segways in Conflicts with Bicyclists, Pedestrians and other Road Users. In *20. EVU Annual Meeting*, 96-103. ISBN 9783851251746.
Pfleger, E.; Jechlinger, Ch. 2010. Disclosure of the Differences in the Navigation and Viewing Behaviour at Day and Night with viewpointsystem® ViewingAnalysis based on Real Examples. In *19th EVU Congress: Prague 2010*, 59-66. ISBN 978-80-7399-136-4.
Pierson, W.R. 1959. The relationship of movement time and reaction time from childhood to senility, *Research Quarterly. American Association for Health, Physical Education and Recreation*, 30(2): 227-231.
Rockar, P.A. 1995. The subtalar joint anatomy and joint motion, *Journal of Orthopaedic & Sports Physical Therapy*, 21(6): 361-72.
Seto, Y.; Minegishi, K.; Yang, Z.; Kobayashi, T. 2004. Research on detection of braking reactions in emergency situations, *Vehicle System Dynamics Supplement*, 41: 784-790.
Spirduso, W.W. 1975. Reaction and movement time as a function of age and physical activity level, *Journal of Gerontology*, 30(4): 435-440.
Wilk, K.E. et al. 1996. A Comparison of Tibiofemoral Joint Forces and Electromyographic Activit During Open and Closed Kinetic Chain Exercises, *The American journal of sports medicine*, 24(4): 518-527.

ESTIMATION OF SIGHT DISTANCE ON HIGHWAYS WITH OVERHANGING ELEMENTS

Iglesias Martínez Luis[1], Castro María[2], Pascual Gallego Valero[3], De Santos-Berbel César[4]
[1] *Depto. de Ingeniería Geológica y Minera, E.T.S.I. de Minas y Energía, Universidad Politécnica de Madrid, Madrid, Spain*
[2,4] *Depto. de Ingeniería Civil: Transporte y Territorio, E.T.S.I. de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Madrid, Spain*
[3] *Depto. de Estructuras y Física de la Edificación, E.T.S. de Arquitectura. Universidad Politécnica de Madrid , Madrid, Spain*

Abstract: Sight distance is a key factor in road safety. Sight distance estimation is usually performed on a digital terrain model (DTM). A DTM is a 3D representation of the terrain surface which depicts exclusively the elevation of the bare ground. However, the reality contains many more elements influencing sight distance than the bare ground. Features such as vegetation, traffic signs, buildings and many other elements are not included in DTMs. The first approximation solution involves the use of digital surface models (DSM), which comprise these roadside features. The use of geographic information systems (GIS) in highway safety research is interesting due to the easy integration of different factors (accidents, traffic data, road features) on the same software platform. However, sight distance studies based on DSM may lead to biased results when there are elements (for example, overpasses, tree branches or cantilever signals) overhanging the roadway that cannot be interpreted by those models. This paper proposes a method to overcome such difficulties. The proposed solution is based on GIS tools (lines of sight) and multipatch datasets, which represent roadside features adequately, added on the DTM. It has been applied in a rural highway located in the Region of Madrid (Spain).

Keywords: road safety, sight distance, geographic information systems.

1. Introduction

Sight distance is a key factor in road safety. In response to this, guidelines for geometric design of roads in different countries set minimum sight distance threshold values (Ministerio de Fomento, 2000; AASHTO, 2011; FGSV, 2012). In order to facilitate the geometric design of roads, some guidelines for geometric design of roads proposes a two-dimensional analytical methodology to estimate available sight distance. Particularly, Easa (2009) devised a 2-D method to calculate sight distance on sag curves with overpasses. Nevertheless, these procedures may not be practical since they consider separately horizontal and vertical alignment, which may lead to overestimate or underestimate the actual available sight distance (Ismail and Sayed, 2007). It is more common instead, to develop an algorithm based on line-of-sight loops on digital terrain models (DTMs), using therefore a 3-D approach. Such procedures retrieve the cross-sectional profile of the terrain below the line of sight between the observer and the target location, identifying any possible obstruction. Ismail and Sayed (2007) devised a precise algorithm to compute the available sight distance. Besides algorithms based on line-of-sight loops, procedures based on viewsheds were developed to study available sight distance of roads (Castro et al., 2011; Jha et al., 2011).
Computer-aided applications for road design estimate and compare available sight distances to stopping sight distance and passing sight distance. They also include visualization tools that simulate the driver’s perspective while travelling (Kühn et al., 2011; Castro, 2012). Such visualization tools are utilized to supervise proper 3-D alignment coordination, yet it requires this checking procedure is performed by experienced engineers (Larocca et al., 2011).
Methods based on line-of-sight loops enable the depiction of sight-distance graphs. These charts represent on the horizontal axis the stations where the driver is sequentially placed, and on the vertical axis the sight distance variables ahead each driver position (Kühn and Jha, 2011; Castro et al., 2014). Besides the comparison available and required sight distances, such charts are advantageous to evaluate the 3-D alignment coordination (Roos and Zimmermann, 2004; Jha et al., 2011; Castro et al., 2015). The German Road and Transportation Research Association provided a framework both for virtual perspective generation and sight-distance graphs on the design of rural highways (FGSV, 2008). Methods based on line-of-sight loops can be implemented on geographic information systems (GIS) (Castro et al., 2014). This approach is interesting because GISs enable that different factors and features may be treated and the data analyzed on a single software platform. For example, factors such as sight distance, geometric design consistency (Dell’Acqua, 2015), accidents, traffic data and road features can be studied together (Altamira et al., 2010; Castro and De Santos-Berbel, 2015).
A DTM is a 3-D representation of the terrain surface which depicts exclusively the elevation of the bare ground. However, the reality contains many more elements influencing sight distance than the bare ground. Features such as vegetation, traffic signs, buildings and many other elements are not included in DTMs. The first approximation solution involves the use of digital surface models (DSM), which comprise these additional roadside features (Khattak and Shamayleh, 2005). DSMs provide, in fact, further information about elements by the roadsides which could reduce the available sight distance. However, the intrinsic features of DSMs make difficult such sight distance analysis when using these entities that do not enable two points on its surface to have the same plan projection while their heights are different. This fact hinders a reliable representation of overhanging features, which is particularly awkward when they

[1] Corresponding author: luis.iglesias@upm.es

are partially located above the road, as occurs for tree crowns or cantilever signals. To overcome this issue, Castro et al. (2016) proposed to remove the overhanging part of these elements from DSMs. Campoy-Ungría (2015) proposed a procedure to estimate available sight distance on highways based on prismatic line-of-sight buffers launched directly on a high-density LiDAR cloud of points, not requiring any terrain surface.
This paper proposes an alternative method to address the problem of overhanging features on the roadway. The proposed solution is based on GIS tools (lines of sight) and multipatch datasets, which represent roadside features adequately, added on the DTM. It has been applied in a rural highway located in the Region of Madrid (Spain).

2. Materials and methods

The first part of this section describes the developed procedure for estimation of sight distance based on GIS tools and multipatch datasets. This procedure was applied to a road with a cantilever traffic signal. The case study is presented in the second part of this section.

2.1. Procedure

The developed procedure for sight distance calculations is performed using a geoprocessing model. This model is based on the use of Construct Sight Lines (ESRI, 2016a) and Line Of Sight (ESRI, 2016b) tools from the 3D Analyst extension of ArcMap. Line Of Sight tool may not only use a DTM and a file containing the points that define vehicle track, but obstructions consisting of a surface (multipatch).
The data required to launch this geoprocessing model comprises the theoretical path followed by a vehicle, a DTM recreating the highway and its roadsides and a multipatch model that includes the possible roadside obstructions to vision. Three stages have been followed so as to enable the study of sight distance:

1) **Terrain model processing**
   The DTM used with this procedure can be obtained from different sources. In this case, a high resolution scanning LIDAR was used to obtain the cloud of points. To create such model, the cloud of points needs first to be processed and classified. Whereas the points within the *ground* class will define the DTM, the points captured on the cantilever signal define another interesting point class in this case study. The scheme in Fig. 1 shows the procedure for processing those data. The point processing includes change of coordinate system as well as automated and manual classification. These operations were carried out using highly efficient, batch-scriptable, multicore command line LiDAR tools. These tools can be run via toolboxes for ArcGIS and are included in the LAStools software suite (Rapidlasso, 2016). The change of coordinate system was performed using *las2las* (transform), ground classification was performed using *lasground*, and manual classification was performed using *LAS datasets* tools of ArcGis,
2) **Construction of multipatch model**
   A multipatch is a 3-D geometry used to represent the outer surface, or shell, of features that occupy a discrete area or volume in 3-D space (ESRI, 2016). This type of geometry can be constructed with other non-GIS 3D software packages such as Collaborative Design Activity (COLLADA) and SketchUp.
   In order to build the multipatch model, the points identified as a cantilever traffic signal during the processing stage were used to set the dimensions of signal. These dimensions were used to define the multipatch model and build the model using 3-D design tools (3D Builder [Microsoft, 2016], and Google SketchUp [Trimble, 2015]). Once the model was built up, an interchange file format COLLADA was used to import the feature into ArcGIS. The exact positioning of model was performed in ArcScene, creating a new multipatch shapefile and using 3-D editor tools,
3) **Geoprocessing model launch**
   Geoprocessing model was built into ArcGis *ModelBuilder*. The procedure proposed was based on *Construct Sight Line* and *Line Of Sight* tools of ArcGis (Fig. 2). Prior to launch *Construct Sight Lines*, it is necessary to convert the 2-D point feature class into a 3-D feature class as well as to input the observer and target point heights. This was made using *Interpolate Shape* and *Calculate Field* of ArcGis tools. In order to apply the *Line Of Sight* tool, the computation model only considers lines matching the observer and stations ahead, up to a maximum given distance. After launching the *Line Of Sight* tool, a *Feature Layer* was created and added to a *Geodatabase*. Finally, detailed sight-distance graphs can be drawn if data are exported to a spreadsheet.

2.2. Case study

The procedure developed was applied on a two-lane rural highway (M-601) located in the Region of Madrid (Spain). A section including a cantilever traffic signal was selected as test site. Fig. 3 shows the actual appearance of the roadway and the roadsides in the section at the cantilever signal position. Fig. 4a shows the vertical alignment of the highway around the cantilever signal, located at station 950, on a grade between a crest vertical curve and a sag vertical curve. Fig. 4b shows the plan view, where the cantilever signal is on a tangent located after a horizontal left curve and before a roundabout followed by a horizontal right curve. The crest vertical curve overlaps, approximately, the horizontal left curve and the sag vertical curve matches, approximately, the horizontal right curve.

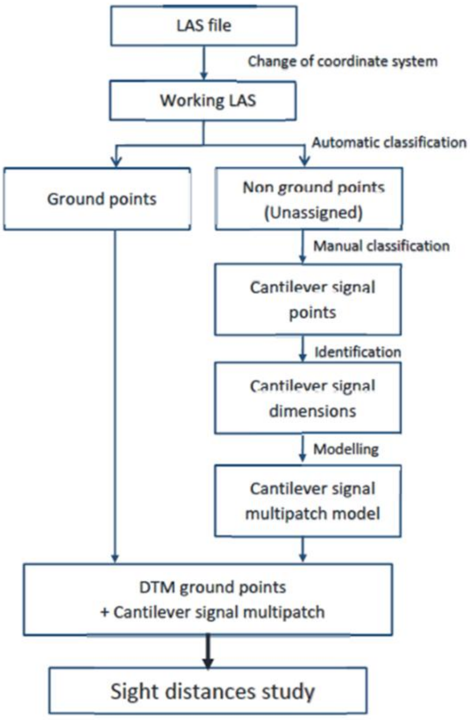


Fig. 1.
Terrain model processing schema

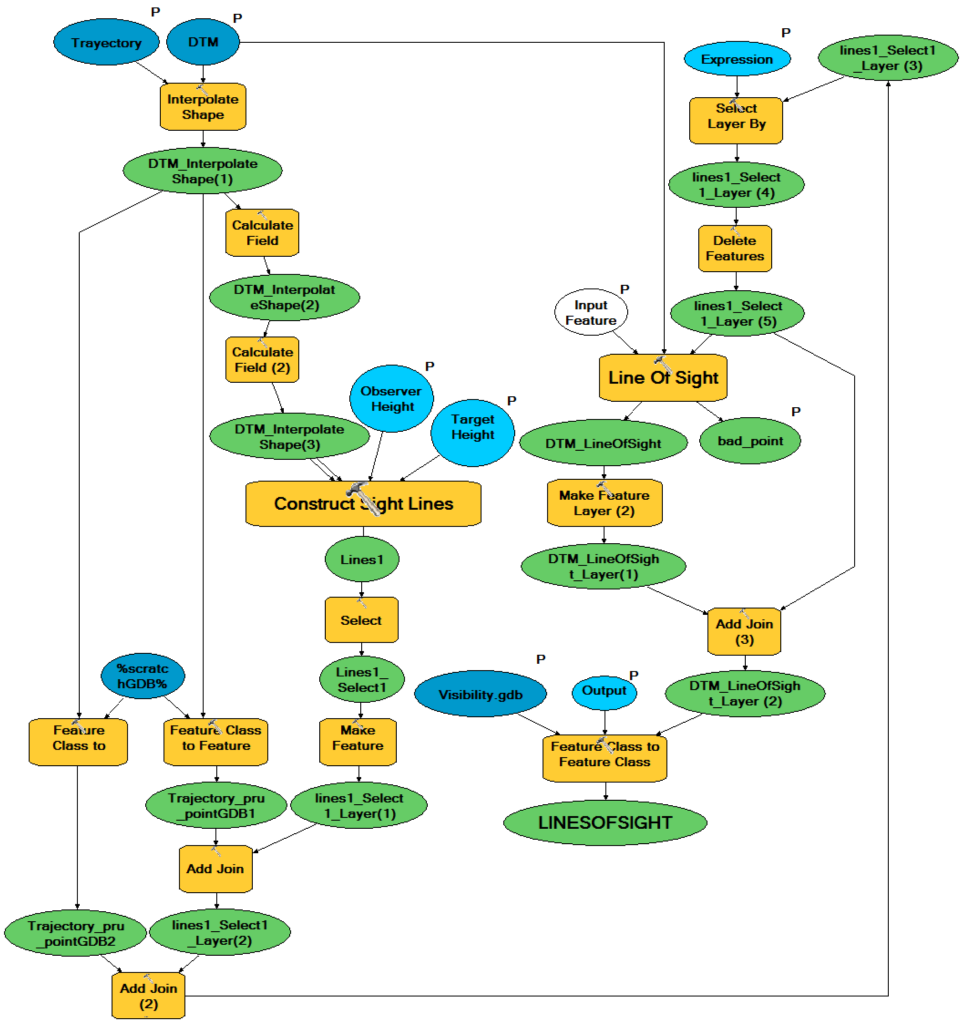


Fig. 2.
Flowchart of the geoprocessing model

Fig. 3.
Test site with cantilever traffic signal

First, in order to validate the new geoprocessing model, its performance is to be compared with the previous Add-in, developed by the authors (Castro et al., 2014), through the calculation of sight distance in four scenarios:

- Scenario 1: Using the previous Add-in and DTM (without cantilever signal),
- Scenario 2: Using the previous Add-in and DSM (including intrinsically cantilever signal),
- Scenario 3: Using the new geoprocessing model and DTM (without cantilever signal),
- Scenario 4: Using the new geoprocessing model and DSM (including intrinsically cantilever signal).

In these four previous scenarios, sight distance parameters took values according to the Spanish highway design standard (Ministerio de Fomento, 2016):

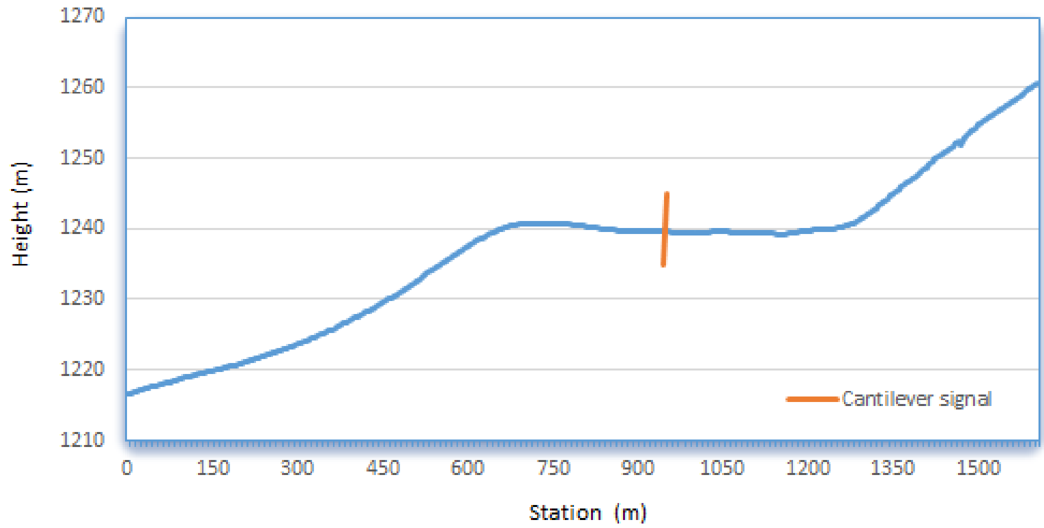
- Vehicle path: 1.5 m from the centerline,
- Driver's eye height: 1.1 m,
- Target object height: 0.5 m/

The vehicle path was extracted from the cartographic data of the highway. The two procedures for calculating sight distance use an algorithm based on line-of-sight loops, hence the vehicle path has to be defined as a discrete set of stations. They are spaced 5 meters apart along such path, where driver and target are successively placed while performing the loop. From each of those stations where the driver's eye is located, the application checks whether a target located in the stations ahead is actually seen or, on the contrary, the line of sight is intercepted by the DTM surface.

In all cases, roadway and roadside were modelled from a high-resolution set of 3-D points. These points were obtained through three LiDAR devices mounted on a car travelling along the road (Mobile Mapping System IPS2-Compact of Topcon). There were two sideward-oriented laser devices and a third one downward oriented, all of them installed at vehicle rear. Other components of the equipment are used for locating and orientating the survey. The GNSS device provides geospatial position, IMU device provides orientation and odometer the distance travelled, speed and angle of rotation of the vehicle wheels (Topcon, 2010). Vehicle speed during data collection was circa 50 km/h; consequently, the set of points is arranged in 12-centimetre spaced cross sections. As mentioned in previous section, the LiDAR devices saved the points in LAS format. Then, the LAS file was processed through the software LASTools so as to be usable on ArcGIS.

Additionally, four scenarios were studied using the new geoprocessing model, the DTM and the cantilever signal (modelled as a multipatch). As mentioned in the previous section, two pieces of software were used in order to build up the cantilever signal multipatch: 3D Builder (Blender) and SketchUp. The first one was used to build the model and the second one to export it as COLLADA format file. Finally, the COLLADA file was imported in ArcGIS. The characteristics of these four scenarios, including cantilever signal multipatch to validate the new procedure, were:

- Scenario 5: Using the new geoprocessing model, DTM (without cantilever signal) and cantilever signal modelled by multipatch. Vehicle path: 1.5 m from the centerline; driver's eye height: 1.1 m; target object height: 0.5 m,
- Scenario 6: Using the new geoprocessing model, DTM (without cantilever signal) and cantilever signal modelled by multipatch. Vehicle path: 1.5 m from the centerline; driver's eye height: 2.5 m; target object height: 0.5 m,
- Scenario 7: Using the new geoprocessing model, DTM (without cantilever signal) and cantilever signal modelled by multipatch. Vehicle path: 1.5 m from the centerline; driver's eye height: 6 m; target object height: 0.5 m,
- Scenario 8: Using the new geoprocessing model, DTM (without cantilever signal) and cantilever signal modelled by multipatch. Multipatch was displaced to station 900 m. Vehicle path: 1.5 m from the centerline; driver's eye height: 6 m; target object height: 0.5 m.



a)

b)

Fig. 4.
a) Road vertical alignment (profile view); b) plan view showing stations and the cantilever signal location (scenarios 1 to 7)

3. Results and discussion

Sight distance was studied for the validation of the new procedure on the eight scenarios set out and analyzed through the corresponding sight-distance graph. It is a chart in which stations are on the horizontal axis and sight distance, measured along the vehicle track, is on the vertical axis. Each green cell represents stations ahead the driver that are seen while the red ones depict non-seen stations, at the distance given by the vertical axis. Finally, the chart is characterized by a blue line which quantifies the available sight distance at each station.
Fig. 5 shows the different sight distance outcomes of the scenarios 1 to 4. Fig. 5a shows the sight-distance graph corresponding to scenario 1 (i.e. using the previous add-in and DTM). In this graph, the available sight distance decreases between stations 480 and 650 due to the horizontal left curve and the vertical crest. In contrast, it increases again as the driver leaves these alignments behind. Fig. 5b shows the sight distance results corresponding to scenario 2

(i.e. using the previous add-in and DSM, including cantilever traffic signal). Although the results of scenario indicate that there is a strong reduction of the available sight distance down to zero as the driver approaches the cantilever traffic signal (station 950), the actual visibility conditions greatly differ from that as it can be noticed in Fig. 3. This bias in the results flags the issue when using DSM since cantilever features cannot be shaped. Fig. 5c shows the sight distance results corresponding to scenario 3 (i.e. using the new geoprocessing model and DTM). Results from scenario 1 and 3 match at 99%. Similarly, Fig. 5d shows the sight distance outcome corresponding to scenario 4 (i.e. using the using the new geoprocessing model and DSM, including cantilever traffic signal). As occurred in scenario 3, there is a biased result in scenario 4 on the section prior to the cantilever signal. Likewise, results from scenario 2 and 4 match at 99%. Both scenarios 2 and 4 highlight the problems of sight distance studies based on DSM when there are elements such as the cantilever signal overhanging the roadway that cannot be correctly interpreted by those models.

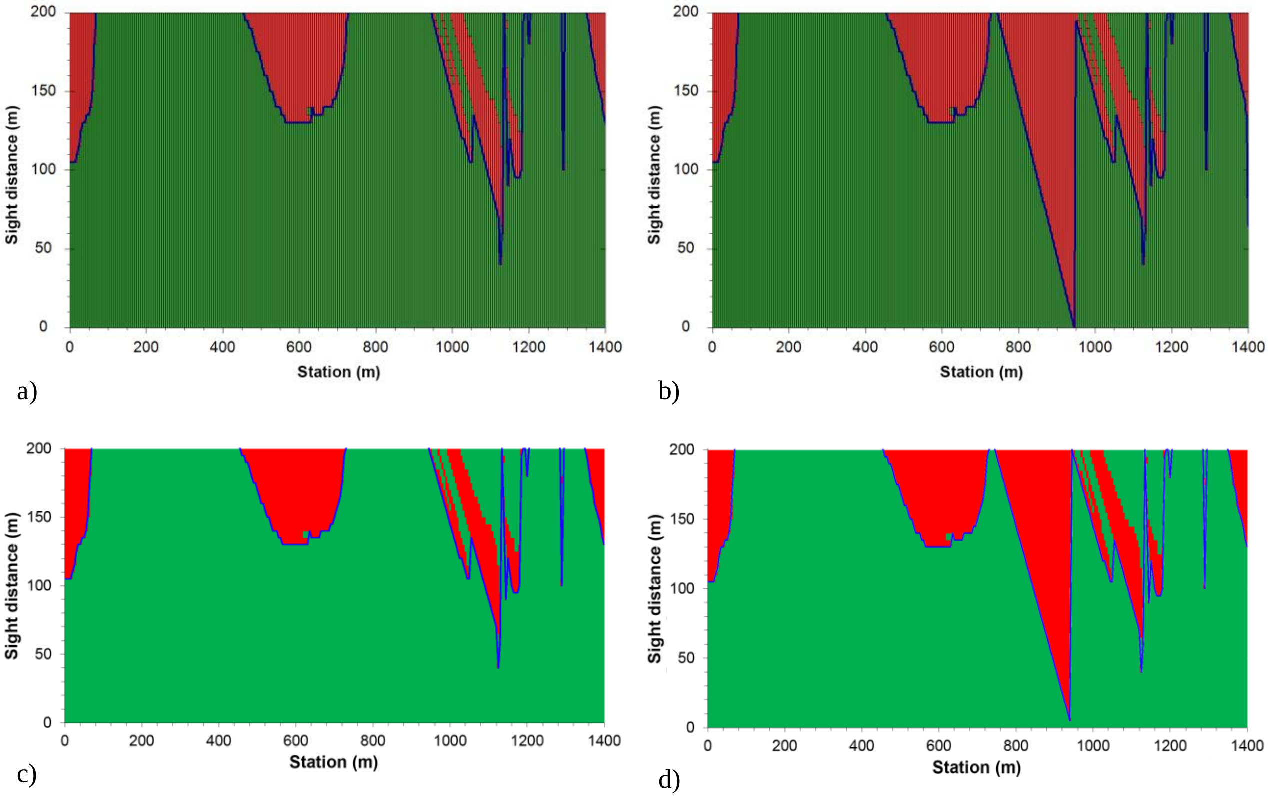


Fig. 5.
Sigh distance results: a) Scenario 1 (using the previous Add-in and DTM, without cantilever signal); b) Scenario 2 (using the previous Add-in and DSM, including cantilever signal); c) Scenario 3 (using the new geoprocessing model and DTM, without cantilever signal); d) Scenario 4 (using the new geoprocessing model and DSM, including cantilever signal)

On the other hand, Fig. 6 (scenarios 5 to 8) shows the outcome of the new procedure based on the new geoprocessing model, the DTM and the multipatch (the cantilever signal is modelled as a multipatch). Note that the new procedure, based on the geoprocessing model, uses the ArcGIS function *Line Of Sight* whilst the previous procedure (Add-in) use the ArcGIS function *Get Line of Sight*. *Line of Sight* function considers multipatches as possible hindrances to vision while the *Get Line of Sight* function does not. In the case of a car driver (driver’s eye height = 1.1 m), the cantilever signal does not reduce visibility (Fig. 6a). This occurs because the height of top and bottom parts of the cantilever signal above the terrain are, respectively, 7.5 and 4.5 m. It would be more likely that the cantilever signal reduces the visibility in the case of a truck driver (driver’s eye height = 2.5 m), but as this cantilever signal is on a grade, this does not happen either (Fig. 6b). From the comparison of Fig. 6a and 6b, it can be deduced that visibility conditions are more favorable for the truck driver than for the car driver as the red area in the chart is more reduced. These scenarios (5 and 6) show that the new procedure provides unbiased results (in agreement with the fact that the line of sight goes under the cantilever signal). However, in order to validate the new procedure, it is necessary to simulate a case where lines of sight intersect the traffic signal. Thus a driver’s eye height of 6 m was considered in scenario 7. Fig. 6c (scenario 7) shows indeed a sharp decrease of the available sight distance due to the traffic signal around station 950.
Furthermore, multipatch objects could be placed easily at any location. In this way, object (multipatch) location effect on visibility could be easily simulated. Fig. 6d (scenario 8) shows sight distance diagram corresponding to traffic signal location at station 900, displacing the multipatch backwards. In this case, the available sight distance is reduced due to cantilever signal at around station 900.

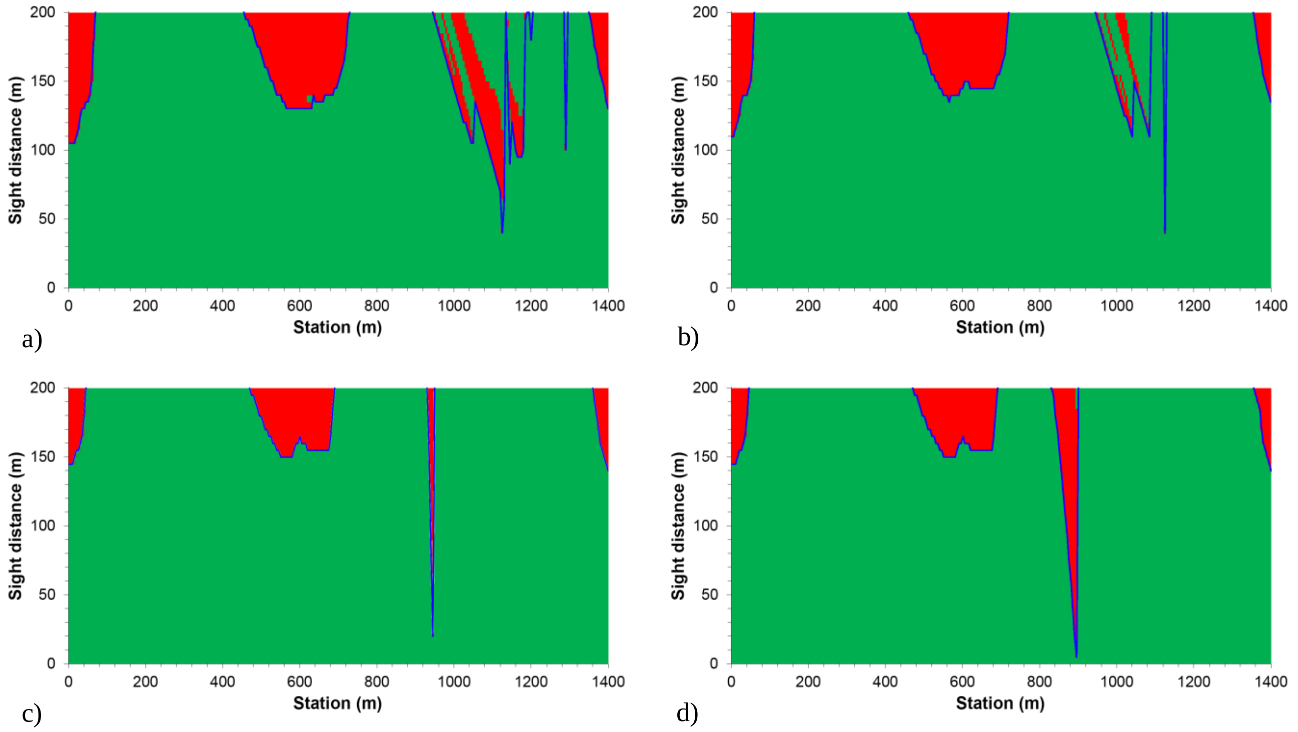


Fig. 6.
Sight distance results using the new geoprocessing model, DTM and cantilever signal modelled by a multipatch: a) Scenario 5 (driver's eye height: 1.1 m); b) Scenario 6 (driver's eye height: 2.5 m); c) Scenario 7 (driver's eye height: 6 m); d) Scenario 8: cantilever signal were moved to station 900 m; driver's eye height: 6 m

In this case study, the multipatch was built from a real element of the highway whose dimensions were determined by LiDAR surveying. However, due to the availability of multipatch datasets libraries, these studies could also be directly inserted. In this way, several objects could be simulated with less effort.

4. Conclusions

A new 3-D procedure for sight distance estimation was developed that overcomes the difficulties inherent to the presence of overhanging elements. This procedure was checked and validated by means of a comparison with a previously developed procedure. The new procedure is able to yield an unbiased sight distance outcome since, unlike procedures based exclusively on DTMs or DSMs, it builds up a real 3-D depiction of the highway and its roadside features. It may be useful, for example, to model either brand new or already-built highways where overhanging elements influencing sight distance such as trees or gantries could be present. This fact was shown by means of the cantilever traffic signal case study.
The easiness to place multipatch objects is an additional advantage provided by this procedure. This simplifies the simulation of object location to evaluate its possible effects on sight distance. Also, due to the availability of multipatch datasets libraries, modelling effort is reduced. Therefore, several objects on diverse locations could be easily simulated. Moreover, the use of GIS offers further advantages owing to its capabilities, the data integration, information management and analysis tools. Therefore different factors such as sight distance, accidents, operating speed, traffic volume and geometric features can be treated and analyzed on a single software platform.
As future lines of research, authors plan to apply this procedure to analyze the effect of overhanging elements on sight distance at or near sag vertical curves, overlapped with different alignments on the horizontal plan. Elements such as cantilever traffic signals could reduce drivers' available sight distance. Factors such as traffic signal location (station along the road), signal dimensions, clearance height and highway geometric design features will be taken into account.

Acknowledgements

The authors gratefully acknowledge the financial support of the Spanish Ministerio de Economía y Competitividad and European Regional Development Fund (FEDER). Research Project TRA2015-63579-R (MINECO/FEDER).

References

Altamira, A. L. Marcet, E.J; Alberto B. Graffigna, B.A; Gómez, M.A. 2010. Assessing available sight distance: an indirect tool to evaluate geometric design consistency. In *Proceedings of the 4th International Symposium on Highway Geometric Design*.

American Association of State Highway and Transportation Officials (AASHTO) 2011. *A Policy on Geometric Design of Highways and Streets*, AASHTO, Washington, D.C., U.S.A.

Castro, M.;Iglesias, L.; Sánchez, A.J; Ambrosio, L. 2011. Sight distance analysis of highways using GIS tools, *Transportation Research Part C: Emerging Technologies*, 19(6): 997-1005.

Castro, M. 2012. Highway design software as support of a project based learning course, *Computer Applications in Engineering Education*, 20(3): 468-473.

Campoy-Ungría, J.M. 2015. *Nueva metodología para la obtención de distancias de visibilidad disponibles en carreteras existentes basada en datos LiDAR terrestre*. Doctoral dissertation. Universidad Politécnica de Valencia, Valencia, Spain.

Castro, M.; Anta, A.J; Iglesias, L.; Sánchez, J.A. 2014. GIS-based system for sight distance analysis of highways, *Journal of Computing in Civil Engineering*, 28(3): 04014005.

Castro, M. de Blas, A.; Rodríguez-Solano, R.; Angel Sánchez, J. 2015. Finding and characterizing hidden dips in roads, *Baltic Journal of Road and Bridge Engineering*, 10(4): 340-345.

Castro, M; De Santos-Berbel, C. 2015. Spatial analysis of geometric design consistency and road sight distance. *International Journal of Geographical Information Science*, 29(12): 2061-2074.

Castro, M.; Lopez-Cuervo, S.; Paréns-González, M.; de Santos-Berbel, C. 2016. LIDAR-based roadway and roadside modelling for sight distance studies, *Survey Review*, 48(350): 309-315.

Dell'Acqua, G. 2015. Modeling driver behavior by using the speed environment for two-lane rural roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2472(1): 83-90.

Easa, S. 2009. Improved sight distance model for sag vertical curves with overpasses, *Transportation Research Record: Journal of the Transportation Research Board*, 2120(1): 28-36.

ESRI 2008. The Multipatch Geometry Type. An Esri White Paper. Available from Internet: <https://www.esri.com/library/whitepapers/pdfs/multipatch-geometry-type.pdf>.

ESRI 2016 a. Construct Sight Lines. ArcGisTools reference. Available from Internet: <https://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/construct-sight-lines.htm>.

ESRI 2016b. Line Of Sight. ArcGis Tools reference. Available from Internet: <https://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/line-of-sight.htm>.

Forschungsgesellschaft Für Strassen- und Verkehrswesen (FGSV) 2008. *Hinweise zur Visualisierung von Entwürfen für außerörtliche Straßen (H ViSt)*, FGSV, Cologne, Germany.

Forschungsgesellschaft für Strassen- und Verkehrswesen (FGSV). (2012). *Richtlinien für die Anlage von Landtraßen (RAL)*, FGSV, Cologne, Germany.

Ismail, K.; Sayed, T. 2007. New algorithm for calculating 3D available sight distance, *Journal of Transportation Engineering*, 133(10): 572-581.

Jha, M.K.; Karri, G.; Kuhn, W. 2011. New three-dimensional highway design methodology for sight distance measurement, *Transportation Research Record: Journal of the Transportation Research Board*, 2262: 74-82.

Khattak, A. J.; Shamayleh, H. 2005. Highway safety assessment through geographic information system-based data visualization, *Journal of Computing in Civil Engineering*, 19(4): 407-411.

Kühn, W. et al. 2011. Workplace simulator for geometric design of rural roads. *Transportation Research Record: Journal of the Transportation Research Board*, 2241:109-117.

Larocca, A. P. et al. 2011. First steps towards the evaluation of the efficiency of three-dimensional visualization tools for detecting shortcomings in alignment's coordination. In *Proceedings of the 3rd International Conference on Road Safety and Simulation*.

Microsoft 2016. 3D Builder user's guide. Available from Internet: <https://developer.microsoft.com/en-us/windows/hardware/3d-builder-users-guide>.

Ministerio de Fomento 2016. Norma 3.1-IC: Trazado, Madrid, Spain.

Rapidlasso 2016. LAStools. Available from Internet: <https://rapidlasso.com/lastools/>.

Roos, R.; Zimmermann, M. 2004. Quantitative methods for the evaluation of spatial alignment of roads, In *Proceedings of the 2nd International Conference of Società Italiana di Infrastrutture Viarie (SIIV).*

Topcon 2010. IP-S2 specifications. Available from Internet: <http://www.topcon.co.jp>.

Trimble 2015. Sketchup PRO. Available from Internet: <http://buildings.trimble.com/products/sketchup-pro>.

COME RAIN OR SUNSHINE: REVEALED DIFFERENCES IN OBJECTIVE AND SUBJECTIVE USAGE OF ELECTRIC-DRIVE COMMERCIAL VEHICLES

Tadej Brezina[1], Maximilian Leodolter[2], Alexandra Millonig[3]
[1] *Vienna University of Technology, Institute of Transportation, Research Center of Transport Planning and Traffic Engineering,Vienna, Austria*
[2,3] *Austrian Institute of Technology, Mobility Department, Business Unit Dynamic Transportation Systems, TECHbase Vienna, Vienna, Austria*

Abstract: Delivery and business-services based on electric-drive vehicles are increasingly seen as components of an environmentally and socially compliant urban transport system. A model region named "e-Mobilty on Demand" was set up by Vienna's municipal utilities company which included the sponsorship for electric company cars – delivery or assembly vans – for various types of businesses. The authors were commissioned to study seasonal and weather-related influences on driver behaviour characteristics (e.g. speed, travel time, charging behaviour). A fleet of thirty cars from four different businesses were equipped with GPS-recorders and manual mobility logbooks. The businesses were two medium sized (tinsmith, chimney-sweeper) and two large sized (electricity supplier, telecommunications provider) companies. The survey took place over four periods of time: February/March and May/June in 2014 and 2015. The GPS data was connected with detailed temperature and sunshine duration records, as their impact has the biggest impact on battery life and performance. Their impact on driving behaviour was examined by means of cluster analysis. Additionally 66 drivers responded to an online survey on perceptions and experiences regarding electric vehicle usage. On average, trips took 20 min, went over a distance of 7 km and had a speed of 39 km/h. In a detailed analysis of driving speeds, trip durations and lengths for different weather conditions no significant impact could be found. The hypothesis of a weather-based change in usage could not be supported, neither concerning length nor duration of trips or driving speeds. Logbook data analysis showed a significant share of en-route battery charging taking place outside the batteries' recommended state of charge. The online survey shows that the participating drivers claim to adapt their driving behaviour to climate conditions, a notion which could not be backed by objective GPS data. Future work could deal with differences in driving behaviour of private and company cars.

Keywords: electric commercial vehicles, company fleets, electric driving behaviour, weather impact.

1. Introduction

In the framework of the Vienna public utility company's model region "e-Mobility on Demand", battery electric drive vehicles (BEV) were included in business fleets by different companies. The model region focuses on the practical use of electric drive vehicles differs instead of conventional fossil-driven vehicles. The task of our research was to survey whether differences in subjective and objective user behaviour could be identified under different weather conditions in terms of number of trips, length of trips and speed (Brezina, T., et al. 2015; Leodolter, M., et al. 2015). As the survey was commissioned after the adoption of BEV to the model region, no differences between fossil fuel vehicles and BEVs could be studied. One major barrier to introducing BEVs is the fear of potential users that range would be insufficient in comparison to fossil fuel vehicle standards (Franke, T., et al. 2012; Prandtstetter, M., et al. 2013). Car buyers seem to prefer vehicles with high available range, although these preferences decrease with practical EV experience (Franke, T. and Krems, J. F. 2013). Not only is range anxiety considered as an introduction barrier among potential users, but research also predicts meteorological influences on energy demand as a base of range optimization (Yuksel, T. and Michalek, J. J. 2015; Viehl, A., et al. 2016). Range anxiety and auxiliary energy demand have been subject of previous research (Graser, A., et al. 2014; Asamer, J., et al. 2016). Our study departs from previous studies by objectively surveying user notions of range anxiety and battery insufficiency in the field of commercial vehicle usage.
In the following section the materials and methods that were used are introduced. Section three summarizes the results of both, subjective and objective data, and in the final section the results are briefly discussed and conclusions based upon them are drawn.

2. Materials and Methods

In order to develop a comprehensive picture of behavioural patterns between summer and winter operations, a tri-polar research design was chosen (Fig. 1). The survey took place over four two-month-periods, in order to cover the widest possible spectrum of seasonal and weather-induced potential influences on driving behaviour:

- February & March 2014,
- May & June 2014,
- February & March 2015,
- May & June 2015.

[1] Corresponding author: tadej.brezina@ivv.tuwien.ac.at

Fig. 1.
Tri-polar survey design incorporation: GPS tracking, manual mobility logbooks and an online user survey to span the bridge between objective movement data and subjective appraisal by users

For the survey of objective behaviour, GPS-recorders and manual logbooks were installed in a fleet of combined 30 cars of two medium sized (tinsmith, chimney-sweeper) and two large sized (electricity supplier, telecommunications provider) companies. The car fleet comprised of following types: Renault (Kangoo, Trafik, Zoe), Tesla (S), Nissan (Leaf) and Citroen (Berlingo, C-Zero). GPS data were revised for errors, stops and finally connected with detailed records of temperature and sunshine duration, as their impact has a significant impact on battery life and performance (Yuksel, T. and Michalek, J. J. 2015).
Subjective appraisal was queried by an online poll that was sent to the users of the car fleet. A total of 26 questions were clustered in three blocks: private interest in e-mobility, appraisal of e-mobility use in business and finally respondent characteristics. The appraisal block included among others questions on in-use experience, charging frequency and the appraisal of the weather's influence.

3. Results

The subjective appraisal resulted in 54.8 % of respondents (n=66) reporting to have experienced special conditions during very hot or/and very cold days (Fig. 2, left). In particular, 43.6 % of respondents reported to have turned off auxiliary functions such as heating, cooling, navigation devices, internal lighting or the radio in order to preserve battery charge. Moreover, 46.2 % of respondents asserted that they schedule their trips in terms of length and duration based on battery conservation (Fig. 2, right).

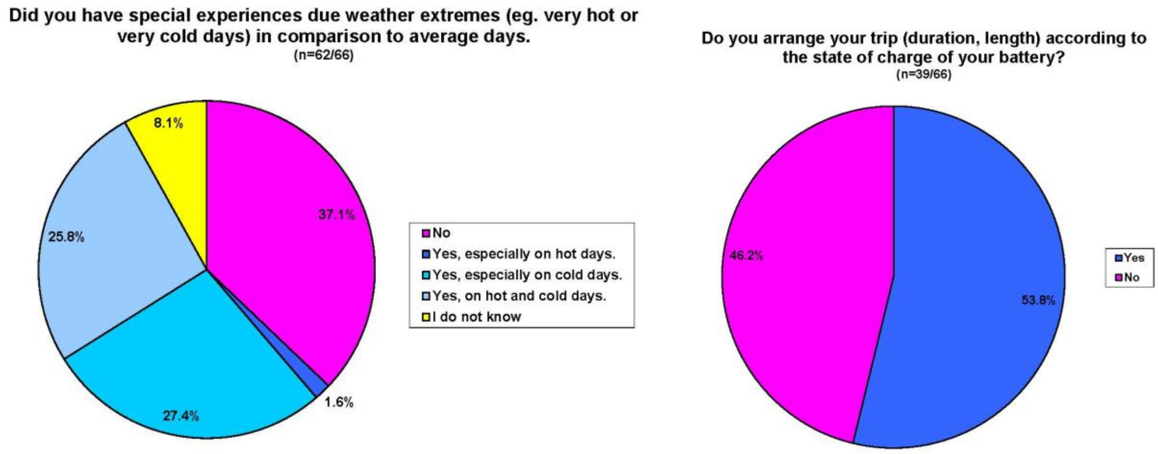


Fig. 2.
Left: A majority of respondents claims to have had special, weather induced experiences with their e-cars in hot and/or cold days. Right: Respondents claim with a majority of 53.8 % to arrange their trips according to trip length or duration

Logbook data analysis on the other hand showed a significant share of en-route (stops outside the vehicle's home base) battery charging taking place outside the batteries' recommended state of charge (SOC). Battery life is enhanced, when they are recharged in a SOC range between 20 and 80 % (Leitinger, C. and Litzlbauer, M. 2011; Budde-Meiwes, H., et al. 2013). Batteries shall therefore never be recharged neither full nor empty. Recharging data shows that about 30 % of the recharging took place in the non-recommended SOC range (Fig. 3, left). E-vehicle users were also asked to rate the additional loading (materials, tools, personnel) of their vehicle for each trip from no additional loading (0) to maximum additional loading (3). When looking at battery recharging from the loading perspective, light additional loading leads to 7-12 % earlier loading. Heavier additional loading leads to less pronounced recharging behaviour (Fig. 3, right). In addition the vehicles in operation were distinguished by type (personal car vs. light-duty commercial vehicle) and by usage profile (permanently assigned to one driver vs. part of a vehicle pool with different users). Similar cumulative frequency distribution reveals that private cars were charged with 10 % fuller batteries in comparison to light-duty commercial vehicle usage. In the SOC range from 45 to 85 %, pool vehicles were charged with approximately 5 % fuller batteries (earlier) than when assigned to one driver only.

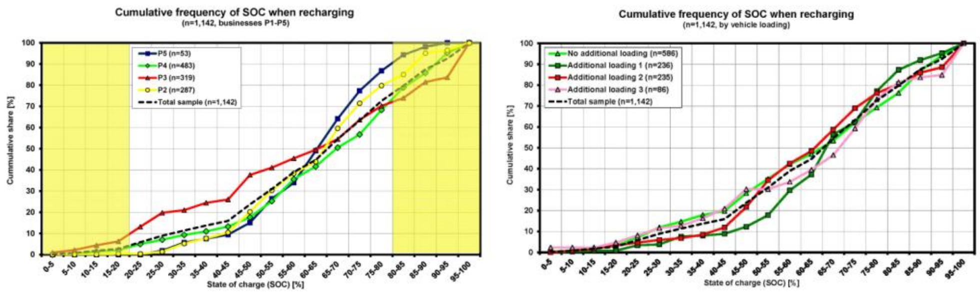


Fig. 3.
Left: Cumulative frequency of SOC when recharging batteries en-route, distinguished by the four participating businesses. Shaded areas indicate SOC ranges that are not recommended for recharging. Right: Cumulative frequency of SOC when recharging the batteries en-route, distinguished by four classes of vehicle loading, from no additional loading (0) to maximum loading (3)

Behaviour parameters from GPS tracking data are presented in Table 1. On average, trips took 20 min, went over a distance of 7 km and reached a speed of 39 km/h.

Table 1
Trip characteristics from GPS data

	Min	Median	Average	Max
Duration [min]	0	15	20	1,377
Distance [km]	0	4	7	287
Velocity [km/h]	1	36	39	148

Fig. 4 depicts distributions of trip durations differentiated by weather conditions, which are represented as weather-classes (e.g.: temperature of -2.9 to 6.8 degrees Celsius and 0 to 38 percent of sunshine per hour). To achieve a continuous data distribution across different weather-classes, the interval borders were defined as the quartiles for the temperature and as the median for the sunshine, respectively. The histograms show highly similar data structures. So, based on this plot significant differences in trip duration could not be expected. Further analysis of the data included similar approaches for the trip speeds. The hypothesis under investigation is that the driving behaviour is similarly adjusted under different weather conditions; e.g. on very hot and very cold days, so that air conditioning and heating affect the driving speed in an analogous way.
The first step towards the examination of this hypothesis is to separate the weather conditions using a finer granulation (see Fig. 5). The second step focuses on finding similarities of these weather classes by performing a clustering based on the Cramér-von-Mises[2] statistic as adjacency measure. The dendrogram in Fig. 6 demonstrates the results of the clustering. The green cluster appears to have a higher median of speed. After omitting the clusters 2, 4, and 6 due to lack of data and small cluster size, only three clusters remain: 1, 3 and 5. A non-parametric permutation test proves that the location shift of the clusters 1 and 3 to cluster 5 are statistically significant. So, taking the weather conditions represented by cluster 5 into consideration, the average driving speed drops by about 2 km/h.

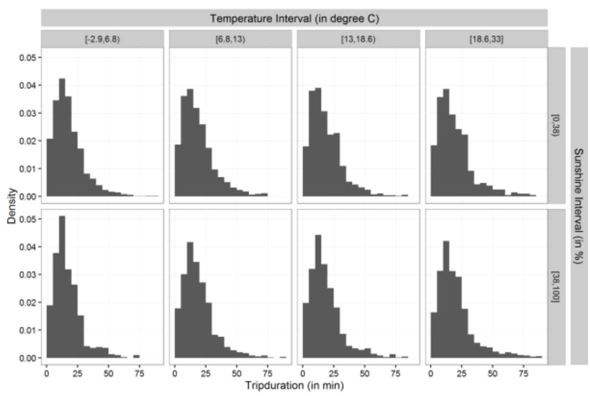


Fig. 4.
Histogram matrix of trip duration in minutes clustered by intervals of temperature (in degrees Celsius) and sunshine duration (in percent)

[2]The Cramér-von Mises statistic is used in statistics to compute the deviations of two empirical cumulative distribution functions (CDF). It is defined by the integral of the squared Frobenius norm of the difference of two CDFs.

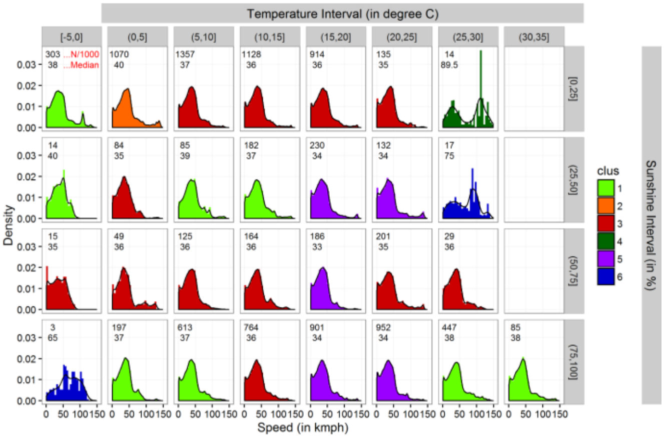


Fig. 5.
Histogram matrix of trip speeds by Cramer-von-Mises statistics, clustered (according to Fig. 6) by temperature and sunshine intervals. The numbers in left upper corner represent the sample size (n/1,000) and the sample's rounded median

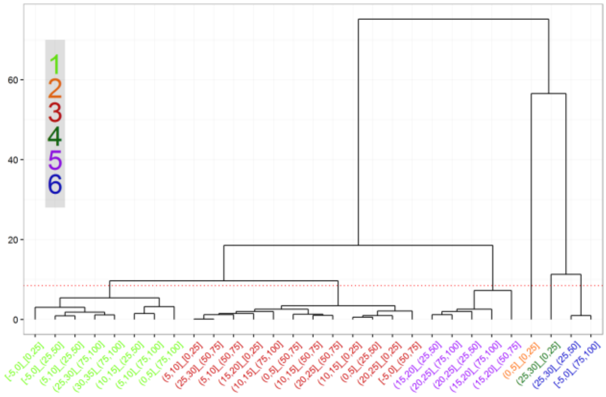


Fig. 6.
Dendrogram (agglomerated, hierarchical clustering) of temperature and sunshine interval samples reveals six clusters

Further in-depth investigation of the speed records and their starting time reveals a possible explanation for the distributions with only non-direct relationships to weather data. An over proportional share of trips of cluster 5 started about 2 hours later than those of cluster 1 and 3. This means that cluster 5 collects mainly trips starting during the morning rush hour, whereas trips of cluster 1 and 3 already start in the early morning hours (Fig. 7, upper). These earlier starting trips may not be hindered in speed choice by the morning peak hour. The morning peak hour reduces cluster five's average speed and thus alters its total distribution. Sunshine duration and temperature are expected to increase during late morning hours. The lower part of Fig. 7 shows the change in speed over the course of the day for the three aforementioned clusters. Therefore, a direct dependency between weather conditions and driving speed cannot be drawn.

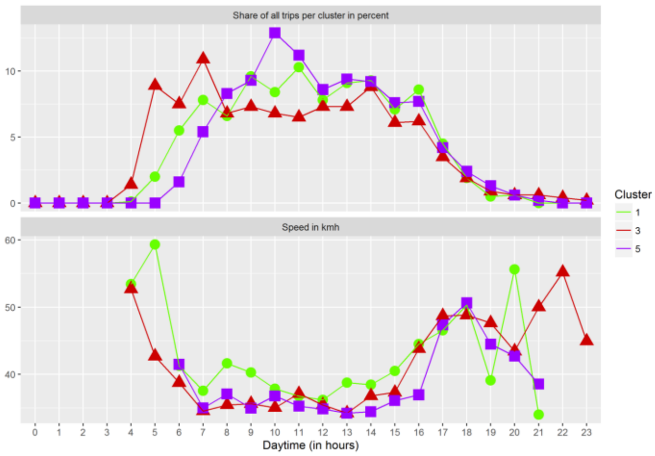


Fig. 7.
Distribution of trip starts for clusters one, three and five (upper) and distribution of average trip speeds (lower) by time of day

4. Discussion and Conclusion

The recorded en-route recharging data show that about thirty percent of recharges take place outside of the recommended SOC. The main reasons may be either driver's lack of knowledge regarding correct recharging procedures or movement-work-pattern constraints – craftsmen recharging their cars when opportunities arise at construction sites and not when it is best for the batteries. While up to 55 % of questionnaire participants stated in the survey that they would act preventively for battery charge conservation under very hot/cold weather conditions by adapting their route choices, a detailed analysis of GPS tracking data could not support these claims. Trip duration and speed datasets were referred to temperature and sunshine interval data. The resulting clusters showed no significant relationships. Subjective driver's notions of adapting their driving behaviour to climate conditions could thus not be backed by our objective GPS tracking data. Neither duration, nor distance, nor velocity showed direct correlation with weather conditions. In the case of one cluster, we speculate that its later trip starts resulted in higher speeds due to the already decreasing morning peak hour. It appears that general insufficiency anxiety of electric vehicles is not based on objective evidence but on other factors, such as individual experience and psychology. Such objective data may provide a sound basis for business decisions concerning car fleets.
Future research may focus on the survey of charging behaviour and movement patterns in depth in order to improve longevity of batteries. Further work could also investigate possible differences in driving behaviour between private and company cars.

Acknowledgements

This research was funded by Vienna public utility company's branch for new mobility "Neue Mobilität Wien Gmbh" as part of the project "e-Mobilty on Demand – Modellregion Wien". Thank you to Eleonora Balaoura for feedback and literature search and to and Ulrich Leth for literature.

References

Asamer, J.; Graser, A.; Heilmann, B.; Ruthmair, M. 2016. Sensitivity analysis for energy demand estimation of electric vehicles, *Transportation Research Part D: Transport and Environment*, 46: 182-199.
Brezina, T.; Genkin, T.; Lemmerer, H.; Leon Manzanares, C.; Pfanner, B.; Shibayama, T.; Toth, P. 2015. *e-Mobility on Demand – Modellregion Wien: Bericht zur Begleitforschung*, TU Wien, Wien, Austria.
Budde-Meiwes, H.; Drillkens, J.; Lunz, B.; Muennix, J.; Rothgang, S.; Kowal, J.; Sauer, D.U. 2013. A review of current automotive battery technology and future prospects. In *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*; 227(5): 761-776.
Franke, T.; Krems, J.F. 2013. What drives range preferences in electric vehicle users?, *Transport Policy*, 30: 56-62.
Franke, T.; Neumann, I.; Bühler, F.; Cocron, P.; Krems, J.F. 2012. Experiencing Range in an Electric Vehicle: Understanding Psychological Barriers, *Applied Psychology*, 61(3): 368-391.
Graser, A.; Asamer, J.; Dragaschnigg, M. 2014. How to Reduce Range Anxiety? The Impact of Digital Elevation Model Quality on Energy Estimates for Electric Vehicles. In *GI_Forum 2014 - Geospatial Innovation for Society*, 165 - 174, Salzburg, Austria.
Leitinger, C.; Litzlbauer, M. 2011. Netzintegration und Ladestrategien der Elektromobilität, *Elektrotechnik & Informationstechnik*, 128(1-2): 10-15.
Leodolter, M.; Millonig, A.; Ray, M.; Reinthaler, M. 2015. *Begleitforschung zur Wiener Modellregion "e-Mobility on Demand"*, AIT - Austrian Institute of Technology, Wien, Austria.
Prandtstetter, M.; Reinthaler, M.; Puchinger, J. 2013. Nur keine Angst, *ATZ agenda*, 2(1): 72-75.
Viehl, A.; Çakar, E.; Engler, M.; Köhler, S. 2016. Wetterdaten in der Reichweitenprognose für E-Fahrzeuge, *ATZ - Automobiltechnische Zeitschrift*, 118(5): 28-35. .
Yuksel, T.; Michalek, J.J. 2015. Effects of Regional Temperature on Electric Vehicle Efficiency, Range, and Emissions in the United States, *Environmental Science & Technology*, 49(6): 3974-3980.

INFLUENCE OF HEADLAMP LIGHTING PARAMETERS ON NIGHTTIME SIGHT DISTANCE

De Santos-Berbel César[1], Castro María[2], Iglesias Martínez, Luís[3]
[1,2] Depto. de Ingeniería Civil: Transporte y Territorio, E.T.S.I. de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Madrid, Spain
[3] Depto. de Ingeniería Geológica y Minera, E.T.S.I. de Minas y Energía. Universidad Politécnica de Madrid, Madrid, Spain

Abstract: Despite the higher accident rates during night driving compared to those in daylight, little research has been conducted on nighttime highway safety. Nighttime sight distance is one of the most relevant factors in night driving. Current design guides provide two dimensional models to study nighttime sight distance in order to design sag vertical curves. These models may, nonetheless, underestimate or overestimate the available sight distance because they do not take account of possible combinations with horizontal alignment nor the actual roadside obstructions. It is therefore necessary to develop a three-dimensional (3D) procedure capable of analyzing the available sight distance under nighttime conditions. This way, it is possible to set the basis of nighttime driving safety research. Thus the study of nighttime sight distance could help in determining whether highway geometric design or headlamp features may influence accident-prone locations. The aim of this study is to analyze the influence of the headlamp lighting parameters on real highways and compare the nighttime sight distance outcome to that in daylight. A GIS-based application for sight-distance studies with a specific tool for nighttime sight distance has been used. The headlamp parameters studied were beam range, headlamp height, upward divergence angle and horizontal spread angle. The analysis has been carried out on different real highways, which enabled the study of the influence of each parameter on different 3D alignments.

Keywords: road safety, nighttime sight distance, headlamp.

1. Introduction

Despite the higher accident rates during nighttime driving compared to those in daylight, little research has been conducted on nighttime highway safety. Nighttime sight distance is one of the most relevant factors in night driving. Studies demonstrated the need for use 3D methods to estimate daytime available sight distance. This fact may also be applied to nighttime available sight distance. Moreover, not only has the combined effect of horizontal and vertical alignments to be known, but also the influence of adjacent alignments is relevant.

When a vehicle traverses a sag vertical curve at night, the stretch of highway illuminated ahead depends on the position of the headlights and the direction of the light beam. Current design guides provide two dimensional models to study nighttime sight distance to design sag vertical curves. However, the diversity of headlight features and layouts has not been properly incorporated in geometric design neither their impact on the visibility conditions produced.

The procedure presented hereby is an extension of the GIS-based daytime sight distance application developed by the authors (Castro et al., 2014). This paper analyzes the effect of headlamp lighting parameters on unlit rural highways under nighttime conditions through the study of an in-service highway.

2. Background

Statistics indicate that nighttime accidents are more frequent than those occurred at daytime even though the traffic volume registered during the night is significantly lower (AASHTO, 2011). In fact, 32 % of fatalities occurred on highways in 2013 in Spain were at dusk or nighttime and 61 % of pedestrians killed befell on rural highways (DGT, 2014). It is therefore necessary to intensify the research on nighttime highway safety.

The enhancement of highway design has produced evident benefits for safety and comfort. However, generous alignments might have also created potential challenges by enabling higher speeds (Dell'Acqua, 2015). On the one hand, Rockwell et al. (1970) reported that drivers adopt higher speeds at nighttime as the available sight distance increases. Limited sight distance under nighttime conditions, on the other hand, reduces reaction chances to road users (Adler et al., 1973).

Design guides propose two-dimensional (2D) analytical methods to device alignments that enable sufficient visibility conditions both on daytime and nighttime conditions (AASHTO, 2011; Ministerio de Fomento, 2016). Recently, the prescriptions for sag curve design were reviewed (Gibbons et al., 2012). It was observed that a static object on the roadway was detected by drivers from distances significantly shorter than those assumed on stopping sight distance models, regardless of the vertical element type. It follows that the limiting factor is often the lighting conditions rather than the highway geometry.

To apply sight distance as design criterion, guides consider separately highway plan and profile. Such practices may nonetheless lead to underestimate or overestimate the actual sight distance yielded as they ignore the combined effect of alignments and roadsides in three dimensions (3D) (Hassan et al., 1997). Ekrias et al. (2008) measured and analyzed traffic lighting features to simulate automobile headlights. Hassan et al. (1997) developed a procedure to compute the available sight distance in 3D on theoretical alignments. Horizontal and vertical curves overlapped were studied. It was

[1] Corresponding author: cesar.desantos@upm.es

observed that a wider horizontal spread angle enhances visibility up to an extent that depends on the highway geometric design. It was also confirmed that superelevation improves visibility. Sivak et al. (1998) evaluated the effects of a variety of factors on the photometric performance of low-beam headlamps.

AASHTO (2011) assumes a headlight mounting height of 0.60 m and a 1 degree as the upward divergence of the light beam from the longitudinal axle of the vehicle. This height value is at odds with that recommended by the Spanish design standard (Ministerio de Fomento, 2016) or the Portuguese one (JAE, 1994), which set the headlight height at 0.75 m. As might be expected, assuming a lower headlight height lays on the safe side. Thus, it is necessary to provide insight on the influence of this height value. For example, the headlight height values of the 11 most sold vehicles (by far compared to the 12th one) in 2015 in Spain, the average is 0.731 m, ranging between 0.658 and 0.858 m. It is important as well to know the effect of the other variables on nighttime sight distance.

Headlamp regulations around the world are not homogeneous even if vehicles put on market are mostly the same. For example, the American standard (ANSI, 2010) is compulsory in the United States and allowed in Canada and Mexico, while the European counterparts (ECE, 1995) required or allowed in most every other country in the world. Whereas European standards are more concerned about headlight glare avoidance with lower beam, which may penalize lighting performance, American standards encourage high headlight performance, at the expense of other users' visual comfort.

An additional issue in nighttime driving is headlight glare. McLaughlin et al. (2005) evaluated discomfort glare experienced by drivers at night. Glare avoidance is primarily considered by standards and automobile manufacturers. In order to reduce the chances of headlight glare, successive regulations diminished the illuminance permitted above the plane defined by the beam axes for the inner headlamp (Gibbons et al., 2012). Current headlamps provide less illuminance above that plane. Thus Hawkins and Gogula (2008) proposed to reduce the upward divergence angle considered for headlight sight distance estimation from 1 degree to a value between 0.75 and 0.9 degrees.

According to the American Federal Motor Vehicle Safety Standards (1991), headlights may be located at a height between 560 mm and 1370 mm. Likewise, the European standard (ECE, 1995) sets the minimum and maximum height at 500 mm and 1200 mm respectively. In line with this, the Italian standard (Ministero delle Intrastrutture, 2001) sets the headlight height at 0.5 m. However, parameters in highway design guides are usually based on outdated vehicle dimensions. Hence Fitzpatrick et al. (1998) characterized modern vehicle headlight heights for their use in geometric design.

The distance to the farthest point covered by light beam depends upon several factors. The first consideration concerns low beam and high beam. Also, the amount of light to consider a point as lit is essential. This implies the analysis of a more complex problem dealing with human vision and perception, affecting as well other two parameters whose influence are hereby analyzed: horizontal spread angle and upward divergence angle. Although many values may be proposed, in general, a range of 70 to 90 m assuming 3 lx as threshold illuminance for low beam could be considered headlamps according to lighting patterns (Boyce, 2009).

Fig. 1 shows the headlights geometric variables and the layout of vehicle headlights in relation to the driver position. The beam axle is parallel to the roadway grade and its heading angle equals that of the vehicle at each station. The upward divergence angle β is measured from the beam axle. The horizontal spread angle α is the angle symmetrically subtended sideward from the beam axle in both headlamps. Distances d_1, d_2 and d_3 define the location of headlamps in relation to the driver. The value d_1 is determined by the distance between the horizontal projection of the driver's eye and the projection of the straight line joining both headlamps. The d_2 is the distance between headlamps and d_3 outlines the lateral offset of the left headlamp relative to the driver, assuming right-hand traffic.

3. Materials and methods

The GIS-based application Road sight distance was utilized to compute the available sight distance (Castro et al., 2014). It has a specific module for nighttime sight distance computation. The algorithm launches lines of sight along a set of stations placed on the driver's path on the highway, evaluating whether those stations are seen from the driver's position. The nighttime module sets a further condition: the target must lie within the light beam. Such light beam comprises the two beams produced by each headlamp which are delimited by the planes defined by the horizontal spread angle, the upward divergence angle and the headlamp range (Fig. 1).

Stations are set all along the theoretical vehicle path spaced 5 meters apart. In this study, the driver's eye height and the target height were set at 1.1 and 0.5 m respectively, in conformity with the Spanish geometric design standard (Ministerio de Fomento, 2016). Likewise, the stations where driver is placed are at an offset of 1.5 m from the outer edge of lane. The beam axle is assumed to be parallel to the gradient of the vehicle travelling on the pavement all the way, which was retrieved from the vertical alignment of the highway. The slope between two successive stations can be taken from the terrain model on the roadway as surrogate value if it is precise enough. Distances d_1, d_2 and d_3 shown in Fig.1 were taken from the average values of the 11 most sold vehicles in Spain: 1.775 m, 1.345 m and 0.32 m respectively.

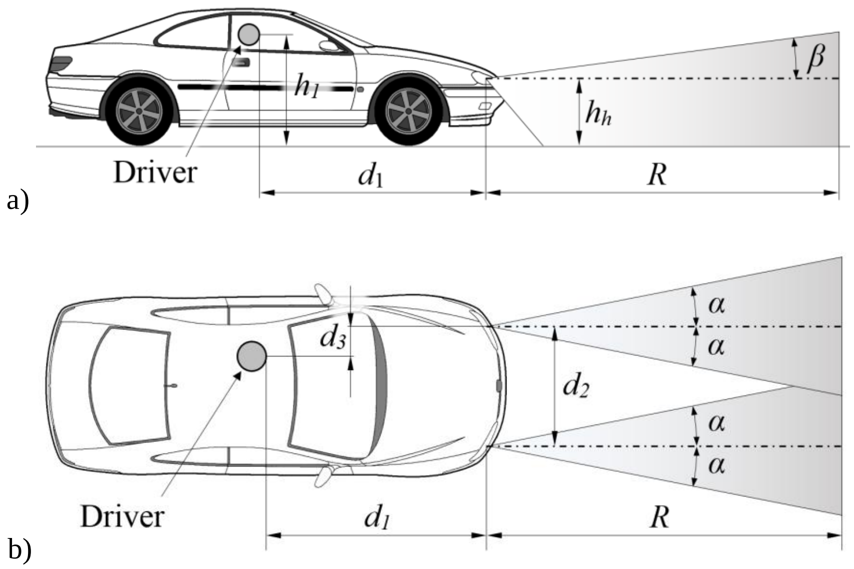


Fig. 1.
Headlamps position in relation to the driver and headlight parameters: a) profile; and b) horizontal projection

The four headlamp parameters to be studied were beam range, headlamp height, beam upward divergence and horizontal spread angle. All values considered in this study for each vehicle headlight parameter are shown in Table 1 which were taken in consistency with the above review of standards and current values. Thus, a total of 900 sets of nighttime sight distance were produced.

Table 1
Headlamp parameters and values studied

Parameters	Values
Beam range	80 m / 100 m / 150 m / 200 m / 300 m
Headlamp height	0.65 m / 0.70 m / 0.75 m / 0.80 m / 0.85 m / 0.90 m
Beam upward divergence	0.7º / 0.8º / 0.9º / 1º / 1.1º
Beam horizontal spread angle	2.5º / 3º / 3.5º / 4º / 4.5º / 5º

A two-lane rural highway was chosen for this study (M-104), which is located in the Region of Madrid (Spain). The length of the section spans 11 km. Its alignment is winding on both the horizontal and the vertical projection, and the design speed is assumed to be 60 km/h. The cross section comprises the roadway of 6.5-meter wide, and 1.25-meter hard shoulder on either side. According to the Spanish geometric design standard (Ministerio de Fomento, 2016), the corresponding stopping sight distance would be 70 m on flat grades. However, the steepest grade reaches 8% on few segments, which means that the stopping sight distance would range from 63 m, when driving uphill, to 79 m, while grade is downhill. The minimum beam range in Table 1 was chosen after this.

4. Results and discussion

First, the consistency of results was analyzed. According to what can be expected, the higher the parameter value is, the longer the nighttime sight distance results for all parameters. Moreover, performing a paired comparison between cases, where all variables remain the same except one, the median results equal or higher in the sample where the variable modified takes a higher value, whatever the variable considered is.
The Wilcoxon signed-rank test for paired samples was performed to determine whether daytime available sight distance and nighttime sight distance come from the same distribution. In all nighttime sets, the p-value resulted less than 0.0001 when compared to the daytime counterparts. It can therefore be rejected at the 99% confidence interval that nighttime sight distance and daytime available sight distance come from the same distribution. The same test was carried out between three relevant headlights cases simulated. Such datasets are those produced by the most favorable parameters (highest input values) , the standard values (beam range 200 m, headlight height 0.75 m, upward divergence 1 degree and horizontal spread 3 degrees), and the most unfavorable parameters (lowest input values). The cumulative frequency graph of these results can also be seen on Fig.2. Even in these cases, the p-value resulted also less than 0.001. Consequently, it can therefore be rejected at the 99% confidence interval that any of these four datasets come from the same distribution.

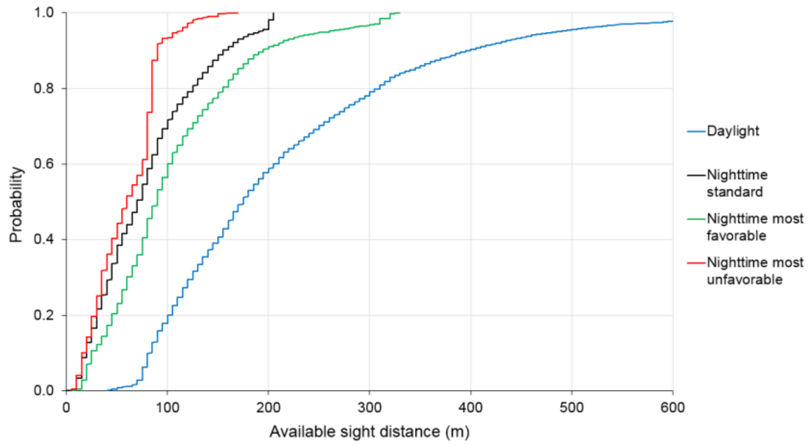


Fig. 2.
Cumulative frequency graph of four relevant available sight distance datasets

It has to be borne in mind that the available sight distance is measured along the vehicle trajectory on the roadway. Conversely, the headlamp range is a straight-line distance. This means that on a winding stretch, the available sight distance outcome may exceed the nominal headlamp range. This fact can be noticed on Fig. 2, where the beam range for nighttime sight distance of the most unfavorable case is 80 m and values over that threshold arose. The same applies to nighttime sight distance in the standard case (beam range: 200 m) and most favorable (beam range: 300 m).
The reader must keep in mind that the lighting range provides the driver with information, among others of the alignment, traffic signs and possible obstacles on the roadway. Notwithstanding the foregoing, the daytime sight distance is still useful in nighttime driving since the field of vision allowed by the roadway and roadside features enable the driver to see other users' headlights and taillights, especially with regard to passing sight distance.
To study the influence of the headlamp range, three series of headlight datasets results were considered, where all parameters are fixed except the beam range. Once again, the first series of results corresponds to the maximum of those values studied (most favorable), the second one set fixes the values at their standard values (headlight height 0.75 m, upward divergence 1 degree and horizontal spread 3 degrees) and the last one takes the most unfavorable ones (minimum values). Fig. 3 shows the share of the overall length where the available sight distance is limited by the headlamp range. While the three series take similar values and show a sharp decrease of sight distance limited for the shortest ranges, the standard and the most unfavorable series present a very low decrease at the highest range around 82 and 85% respectively. Only the most favorable series continues reducing the limitation of the light beam at a moderate rate below 75%. This fact would prove that the rest of parameters are those which enhance visibility conditions to create the evident gap between the most favorable series and the two others. However, if sections with limited sight distance (below values recommended by Spanish standard) are considered exclusively, the influence of headlamp range is null since range is assumed to be no shorter than 80 m.
It is also remarkable that in the case of the winding highway considered in this study, even in the best case, the nighttime sight distance is limited by the light beam along three quarters of the track. Although the geometric design of the highway determines indeed how much of the section ahead is illuminated, it is not the only restrictive factor. It would be interesting to test different roadway scenarios with diverse clearances to study the influence of alignment and roadsides.

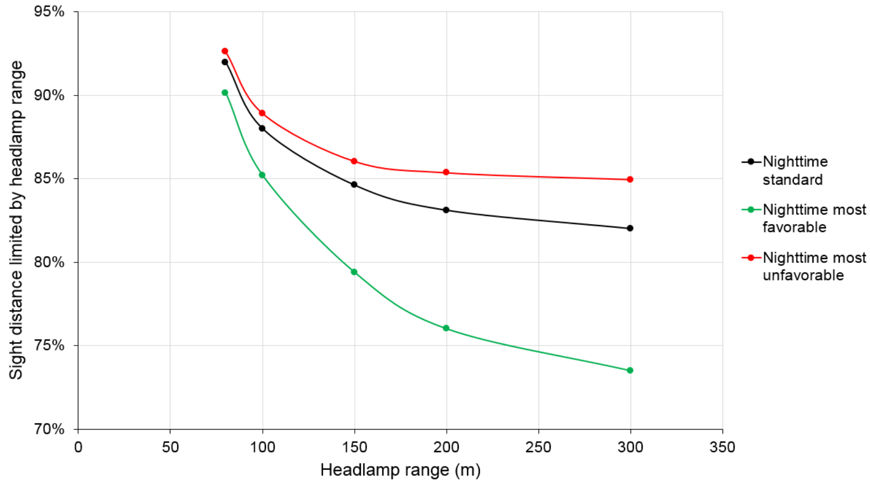


Fig. 3.
Share of nighttime sight distance limited by headlamp range

Next, the influence of headlight height was studied. Likewise, three series of datasets were considered. On each, all the headlight height are considered for the most favorable (maximum values for the other parameters), the standard and the most unfavorable (maximum values for the other parameters). The median of each dataset and the percentage below the available sight distance enforced by the Spanish standard (79 m) were studied to evaluate the influence of this parameter. The median is considered instead of the mean value since the sight distance take discrete values. The consideration of the share of sight distance above the standards permits the study of the influence of this parameter in the lowest tail of the samples, i.e. the zones where the hazard is higher. The results shown in Fig. 4 indicate that this influence is low regardless of the series considered. While the share of sight distance above the stopping sight distance rises slowly, the median values jump just one step (5 meters) in the most favorable and most unfavorable series.

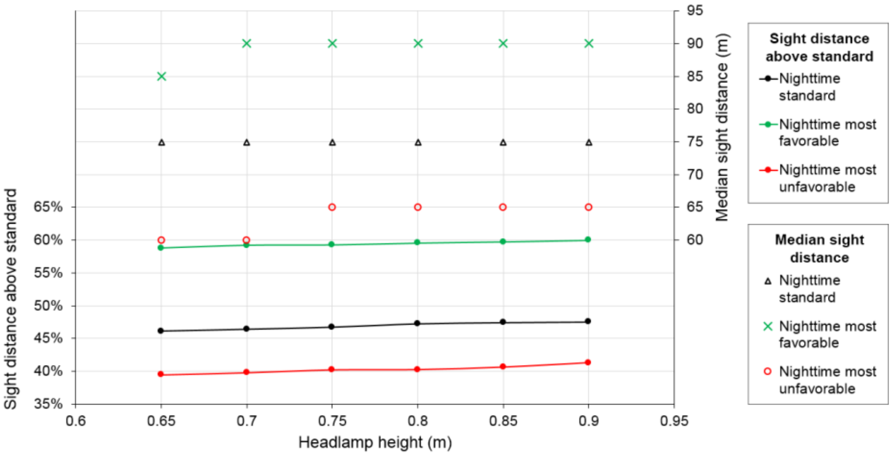


Fig. 4.
Influence of headlamp height on the share of nighttime sight distance above stopping sight distance and median nighttime sight distance

The analysis that follows corresponds to the influence of the beam horizontal spread angle. The usual three series of datasets were considered, varying the value of the horizontal spread angle: the most favorable combination of the parameters, the other standard parameters and the most unfavorable combination of them. The influence of the horizontal angle is significantly higher than in the case of the headlight height because it increases steadily on the three series of data, at a rate of around 5% per degree (Fig. 5). Also, almost every increment of the spread angle entails an increment on the sight distance median. However, the enhancement of the visual field at night as the horizontal spread angle increases is counteracted in terms of safety by the possibility of producing glare to other road users.
Finally, the influence of the upward divergence angle is addressed. As for the previous parameters, the usual three series of datasets were considered while the vertical angle above the beam axle is varied: most favorable, standard and most unfavorable. The results are shown in Fig. 6. Firstly, the variation of the share of sight distance above standard is less close to be linear since a discontinuity around 0.9 degrees is observed for the three series. While the improvement in results is noticeable as the upward divergence changes from 0.8 to 0.9 degrees, it is barely perceptible when the angle is increased to 1 degree. Although the range of the upward divergence at stake is smaller than that of the horizontal spread, the influence of the vertical one is greater per degree. The divergence angle above the beam axle is also hazardous with regard to headlight glare.

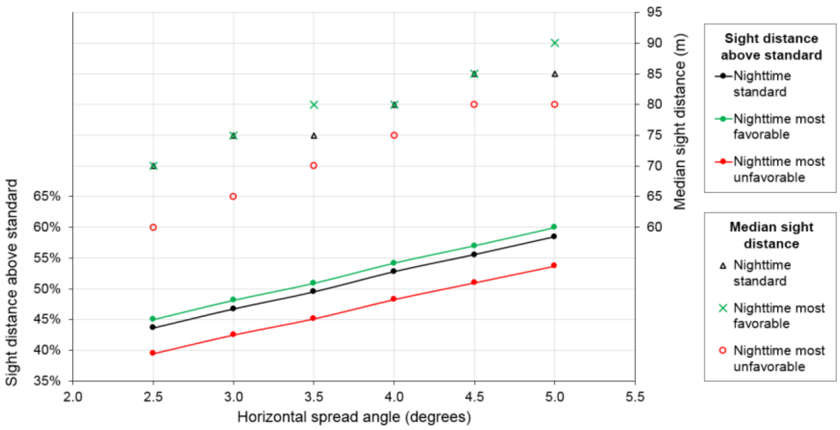


Fig. 5.
Influence of beam horizontal spread angle on the share of nighttime sight distance above stopping sight distance and median nighttime sight distance

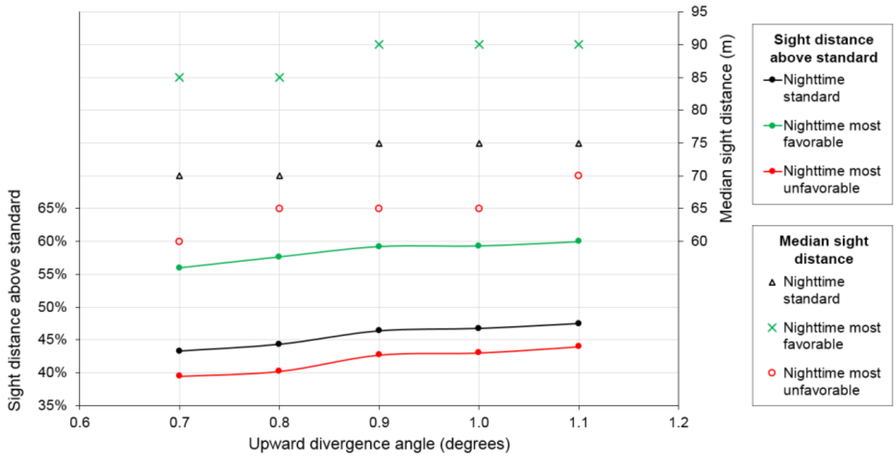


Fig. 6.
Influence of beam upward divergence angle on the share of nighttime sight distance above stopping sight distance and median nighttime sight distance

5. Conclusions

The influence of four vehicle headlight parameters has been studied: headlamp height, beam range, horizontal spread and upward divergence angle. This methodology also sets the basis of nighttime sight distance on driving safety research.

The expected qualitative effect of each parameter was produced in the results, i.e. the nighttime sight distance increased as the parameter values did so. However, the numerical influence of each one was different. It was found that the most influencing parameter was the upward divergence angle, particularly when sight distance are below those recommended by guides. In this case study, the results show that an angle of 0.9 degrees produces nighttime visibility conditions as satisfactory as for the widespread standard value of 1 degree. Also, the influence of the horizontal spread angle is close in importance to the vertical angle above the beam axle. The beam range is nonetheless useful for little in the case of a winding highway such as the case herein addressed.

Although the Spanish standard takes a relatively high headlamp height to study nighttime sight distance, especially when compared to the American one, the results evidenced that the influence of this parameter is very little and the dependences seem much greater for the other parameters. It can be concluded from this that the safety implications of this assumption are not significant. In further studies, the effect of directional headlights on nighttime sight distance is to be analyzed. In addition, different scenarios may be set up in order to test how effective this novel technique results depending on the clearance available in curves.

Acknowledgements

The authors gratefully acknowledge the financial support of the Spanish Ministerio de Economía y Competitividad and European Regional Development Fund (FEDER). Research project TRA2015-63579-R (MINECO/FEDER).

References

Adler, B.; Lunenfeld, H. 1973. *Three beam headlight evaluation. DOT/HS-800-844*. National Highway Traffic Safety Administration, U.S. Department of Transportation Washington, D.C., U.S.A.

American Association of State Highway and Transportation Officials (AASHTO). 2011. *A policy on geometric design of highways and streets*, AASHTO, Washington, D.C., U.S.A.

American National Standards Institute (ANSI). 2010. *Performance requirements for motor vehicle headlamps*, Standard SAE J 1383-2010. SAE International. U.S.A.

Boyce, P.R. 2009. *Lighting for driving: roads, vehicles, signs, and signals*, CRC Press, Boca Raton, U.S.A.

Castro, M.; Anta, J.; Iglesias, L.; Sánchez, J. 2014. GIS-based system for sight distance analysis of highways, *Journal of Computing in Civil Engineering*, 28(3): 04014005.

Dell'Acqua, G. 2015. Modeling driver behavior by using the speed environment for two-lane rural roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2472(1): 83-90.

Dirección General de Tráfico (DGT). 2014. *Las principales cifras de la siniestralidad vial España 2013*. Ministerio del Interior. Spain.

Economic Commission for Europe (ECE). 1995. *Regulation 48: Agreement concerning the adoption of uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions. (Revision 12)*, United Nations, Brussels, Switzerland.

Ekrias, A.; Eloholmaa, M.; Halonena, L.; Songb, X-J.; Zhangb, X.; Wenb, Y.2008. Road lighting and headlights: Luminance measurements and automobile lighting simulations, *Building and Environment*, 43(4): 530-536.

Fitzpatrick, K.; Lienau, T.; Fambro, D. 1998. Driver eye and vehicle heights for use in geometric design, *Transportation Research Record: Journal of the Transportation Research Board*, 1612(1): 1-9.

Gibbons, R.; Flintsch, A.; Williams, B.; Du, J.; Rakha, H. 2013. Evaluation of Impact of Modern Headlamp Technology on Design Criteria for Sag Vertical Curves, *Transportation Research Record: Journal of the Transportation Research Board*, 2384(1): 65-73.

Hassan, Y.; Easa, S.; El Halim, Abd. A. 1997. Modeling headlight sight distance on three-dimensional highway alignments, *Transportation Research Record: Journal of the Transportation Research Board*, 1579(1): 79-88.

Junta Autónoma de Estradas (JAE). 1994. *Norma de Traçado*. Junta Autónoma de Estradas. Portugal.

McLaughlin, S.B. et al. 2005. *Enhanced Night Visibility Series, Volume VII: Phase II—Study 5: Evaluation of discomfort glare during nighttime driving in clear weather (No. FHWA-HRT-04-138)*, Virginia Tech Transportation Institute, U.S.A.

Ministerio de Fomento. 2016. *Norma 3.1-IC: Trazado*, Ministerio de Fomento, Madrid, Spain.

Ministero delle Infrastrutture e dei Trasporti. 2001. *Norme funzionali e geometriche per la construzione delle strade*. Ministero delle Infrastrutture e dei Trasporti, Roma, Italy.

National Highway Traffic Safety Administration. 1991. *Lamps, reflective devices and associated equipment. Federal Motor Vehicle Safety Standards, Standard 108 (49CFR571.108)*: 316–319, 321, NHTSA, Washington D.C., U.S.A.

Rockwell, T.H. et al. 1970. *NCHRP Report 99: Visual requirements in night driving*. HRB, National Research Council, Washington D.C., U.S.A.

Sivak, M., Flannagan, M.J.; Miyokawa, T. 1998. *Quantitative comparisons of factors influencing the performance of low-beam headlamps. Report No. UMTRI 98-042*. The University of Michigan Transportation Research Institute, Ann Arbor, Michigan, U.S.A.

ACCESSIBLE BOARDING FOR RAIL PASSENGERS

Bernhard Rüger[1], Goran Simić[2]
[1] *Vienna University of Technology, Vienna, Austria*
[2] *Belgrade University of Belgrade, Belgrade, Serbia*

Abstract: Regarding to EU regulations today's public transportation systems must be accessible for everyone without any restrictions. The relevant question is: How can trains be accessible for everyone? The huge variety of different vehicles and different platforms does not allow level boarding everywhere, only in so called "closed" systems. The paper gives an overview about the requirements for new boarding assistance systems and about the decision making process referring to a new developed lift system for UIC-coaches. This lift system is developed in the EU-founded project PubTrans4All.

Keywords: accessibility, vehicle entrance, boarding assistance device, PRM.

1. Introduction

The result of the previous work in the PubTrans4All-project, founded by the EU, led to the decision that the most important step towards an accessible rail system at the moment is the development of a boarding assistance system (BAS) for existing UIC wagons. These cars are still in use in large number all over Europe. Due to design limitations it is not possible to retrofit these types of vehicles in order to use existing BAS. So at the moment only platform based BAS can be used for wheel chair users. For all other types of vehicles some kind of BAS exists (lifts for high speed trains, ramps for low floor trains). The aim of further research in this project was to develop a BAS that can be used for installation in UIC wagons.
The layout of older UIC coaches and modern high speed trains that are designed for wheelchair users and other PRMs in general is similar. UIC coaches has small doors with a width of 800, while in modern trains the door width is increased to 900mm. The difference is that there are already lift solutions for a door width of 900mm but none for narrower doors. The UIC coach has doors located at the end of the coaches. Because of the folding or sliding steps as vicinity of the buffers as well as other constraints, there is no space under the steps for the installation of a BAS. Additionally, the space at the coach end is occupied by mechanisms of the head doors leading to the next coach, fire fighting equipment, some electrical components etc. Typical for these coaches is that the passageway is in majority cases at one side outside the longitudinal centre line of the vehicle because of the neighbouring toilet cabins adapted for people with handicaps and persons with reduced mobility. Finally, there are usually only two potential positions left which could be used for stowing the BAS.

2. General requirements for a new boarding assistance system

The general requirements provide an overview of all relevant parameters that must be considered when designing a new boarding assistance system. Table 1 presents the importance scores used in order to rank the evaluation criteria. Table 2a/b summarizes the requirements. Features rated as not important, are not shown herein.

Table 1
Criteria importance scoring

Score	Meaning
1	Very important – critical to successful operation ("must have")
2	Important – high benefit for users and operators ("nice to have")
3	Less important – some benefit for users and operators, but not absolutely necessary

Table 2a
BAS evaluation criteria - overview

User with devices	Wheelchair, walking frame, baby prams	1-2
Physical impaired	Walking disabled, with crutch or sticks, elderly, diminutive people	2
User with special needs	Visual and hearing impaired	2-3
General passengers	Passengers with luggage, children, pregnant	2-3
Operation without staff	Operation by passengers themselves, automation	2

[1] Corresponding author: bernhard.rueger@tuwien.ac.at

Table 2b
BAS evaluation criteria - overview

Operator		
Reliability of BAS	Prevention of Malfunction	1
Operational quality	Short dwell time, malfunctions must not influence train operations	1-2
Operational effort	Number of staff	1-2
Failure management	Problems easy to solve	1
Manufacturing/ Implementation		
Universalism	The system needs to be universal, retro-fitting allowed	1-2
Costs	Costs as low as possible	1
Manufacturing effort	The manufacturing effort needs to be low – especially when retro-fitting	1-2
Safety		
Safety risks	No safety risks to be tolerated	1
Safety features	Optical and audio signals	1-2
Maintenance		
Maintenance effort	Number of personnel required, special tool required	1
Costs		2
Sustainability	Recyclability and energy consumption	3
Aesthetics		
Optical design	Aesthetics is important for customer acceptance	2-3
All regulations must be fulfilled (currently according to TSI-PRM) as a minimum standard. Some specifications in project PT4All have been set higher than required.		

3. Decision making process

At the beginning of the project the consortium consciously set the bar very high in order to get the best possible results. The primary defined goal of the project was to find a technical solution to provide accessibility to all passengers in all boarding situations. To get innovative and completely new ideas, a student competition was also initiated. The consortium believed that students don't have the detailed knowledge about railway vehicles and they are therefore more independent in their thoughts. Experts usually have a tunnel vision because they think too much about reasons why something cannot work.

After a long research and discussion process including the excellent ideas from the competition, the consortium concluded that many restrictions are necessary and the all-in-one solution is not possible. At this point it must not be forgotten that the PubTrans4All project is a research project which also has the goal of demonstrating what is and is not possible.

In the first step, current and future plans of the different railway systems over the whole of Europe have been analyzed in order to identify the biggest gaps.

For all local systems (including busses, tramways, metros, urban and suburban railway traffic) a newly developed BAS is neither necessary nor meaningful. All these systems can be seen as so called "closed systems". Here the operators provide vehicles which correspond to the existing platform height; which means level boarding is provided. If level boarding is not yet provided, then operators plan to adapt the platforms and/or their vehicles. Local traffic operators in general don't want to use technical devices (BAS) because of operational time reasons.

Level boarding is in general the best solution for travelers and for operators. It is the only situation which really offers accessibility to all passengers. Furthermore, the passenger flow in the station can be speeded up which means a shorter dwell time and therefore advantages for operators.

To offer level boarding it is necessary that the platform and the vehicle floor have a common height and the remaining horizontal gap between vehicle and platform is bridged. For that many technical solutions already exist.

For all situations where level boarding is not possible, different approved technical solutions such as ramps or lifts already exist.

Compared to the local traffic systems; high speed, long distance and international railway traffic will not be able to offer level boarding for the following two reasons: The first reason is that because of static, high speed trains need a higher floor. The lowest floor height in high speed trains is offered in Talgo-trains (760mm). All other vehicles have got higher floor height.

The second reason is that in the TSI two different platform heights are defined as European standard (550mm and 760mm). That also means for the next decades all international trains will need to stop at both levels!

Furthermore, the investigation has also shown that actually within the next decades a huge number of high floor vehicles will run in European countries in long distance traffic. Due to the long life cycle of railway vehicles they can't be changed in a short or medium term.

So the decision was to develop a BAS for all types of high floor vehicles. In general there are four possibilities – ramps or lifts, platform or vehicle based.

The operators' surveys clearly show that operators either plan to provide level boarding in the future or – everywhere they cannot – they strongly wish to have vehicle based systems. Two reasons can be identified for that wish: Firstly, operators want to be independent from the infrastructure and want to offer the possibility of accessible boarding everywhere. Secondly, it is very difficult to provide a platform based device at all (!) platforms in a railway network.
In order to provide accessibility to all passengers, ramps seem to be the only possibility because lifts cause a big bottle neck if every passenger tries to use one door. But here the big problem is that it was not possible to find a technical solution for installing a ramp system into existing vehicles. Furthermore, ramps must be very long if they will be used for high floor vehicles.
Because of the impossibility of finding any technical solution for ramps in existing high floor vehicles, the decision was to focus on lift systems for existing high floor vehicles. For the next steps of development two decisions have been necessary: Who the user will be and which vehicles are relevant.
The investigations show that for all types of high floor trains with an entrance door width of at least 90cm, different lift systems already exist. It is not meaningful to develop another system because passenger and operator surveys have shown that the existing systems work well enough.
But there is one very big group of high floor railway vehicles in Europe, the so called UIC-wagons. This is a unique type of vehicle which will be running in many European countries for some decades more. In many countries the UIC-wagons form the backbone of the long distance railway traffic, especially in eastern European countries. But due to many construction limitations described in previous deliverables no technical solution has yet been developed. Therefore, the consortium came to the decision that the most important step to offer accessibility to all is to focus on UIC-coaches!
A lift system under very limited frame condition means many restrictions and compromises. In regard to user requirements, wheelchair users are the only passengers for whom a technical solution is an absolute must. For many other groups it would be very nice to have some technical devices; but if there is no chance, than other solutions are acceptable. As other solutions, special services at the entrance door are recommended within this project. There already exist good examples in different European countries which can be advanced.
At the end of the decision process, it came out that the most important case is to develop a vehicle based BAS for UIC-coaches. Since there are many restrictions because of the vehicle design, it has also for this situation been necessary to define some "compromise solutions" regarding the construction. All recommendations for a vehicle based BAS for UIC-coaches are shown in the next chapter "Detailed technical requirements for a BAS for UIC wagons".

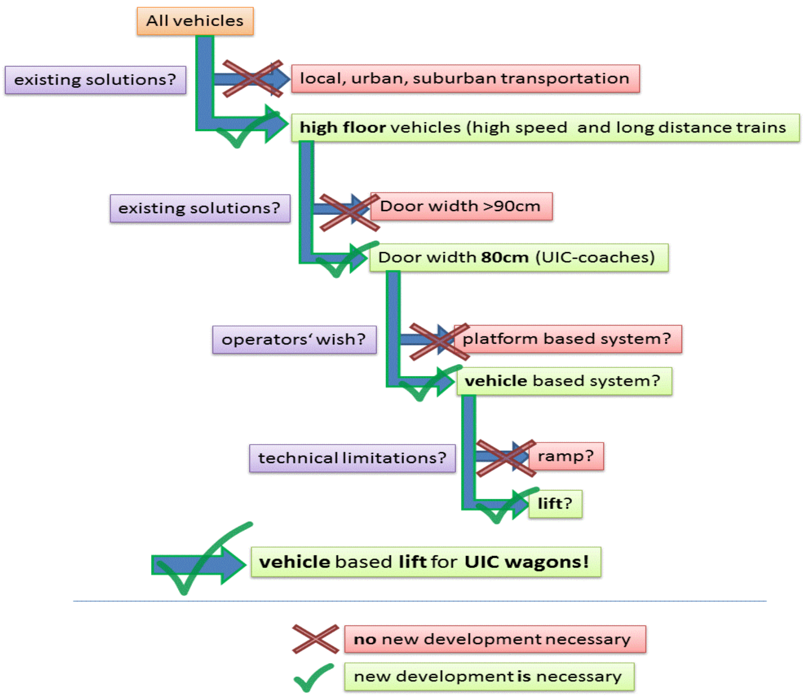


Fig. 1.
Decision making process

4. Technical requirements for a BAS for UIC wagons

As described in the chapter "decision making process" the consortium decided to focus on a BAS that can be implemented into UIC wagons. Therefore, at this point all technical requirements that have been identified especially for the implementation into UIC wagons will be described in detail.

Table 3a
Applicability of a BAS in different vehicles

Characteristic	Value	Comment
Carrying capacity	300kg	Covers 99% of wheelchair users
Minimum clear width of lift platform	720mm	Covers 96% of wheelchair users
Minimum platform length	1200mm	
Maximum working height difference vehicle floor-platform	1300mm	
Distance from the side of the coach when the lift platform is in lowered position:	as small as possible, but not less than 75 mm	The lowest foldable stair required to be lifted up before descending of the lift platform.
Boarding/alighting parallel to the vehicle	recommended	Alternatively, exit sideways through lay down of the side fenders (required for narrow platforms)
Handrail bound to the platform on one side, should be at the height of	650 to 1100mm from platform level	
Integrated folding seat for categories of users other than wheelchair users	recommended	
Finger pressure for activation of control buttons	≤ 5N	
Manual force to operate the lift by staff	≤ 200N	For example for emergency mechanical activation.
Manual force to operate the lift by staff at movement start	≤ 250N	Allowed only for short period at the start. For example for emergency mechanical activation.
Vertical speed in the operation	≤ 0.15 m/s	Movement should be smooth
Operating speed variation: empty-maximum loaded	±10%	
Speed of any point of BAS without load	≤ 0.2 m/s	Up to 0,6m/s is allowed by EN 1756-2. To meet TSI PRM, maximum speed without load no more than 0,3m/s is recommended.
Acceleration during operation with load in any direction and at any point of the lift platform	≤0.3 g	
Tilting speed of the lift platform	≤ 4o/s	In case of automatic adaptation to the relative angle between vehicle and platform, for example at superelevated track by platforms in curves.
Automatic roll-off protection height	≥100mm	The barrier in front and at rear side of the wheelchair lift platform should be automatically erected during lift operation.
Lateral side guards height:	≥25mm min ≥50mm preferred	Prevention of the wheelchair side roll-off from the lift platform
End of travel mechanical limitation devices	yes	
Prevention of any unauthorized operation in the absence of the operator	yes	Locking and unlocking by a key or a code or similar.
Overload protection of the main power electrical circuit		Fuse, an overload cut-out or similar
In stowed position BAS must be safe against uncontrolled displacements. Mechanical securing devices dimensioning according to the accelerations:	alongitudinal=5g alateral=1.5g avertical=1g	These accelerations can arise in the exceptional case of occasionally buffing impact at coach staying in yard (without passenger) (UIC 566)

Table 3b
Applicability of a BAS in different vehicles

Characteristic	Value	Comment
Activation possible only at:	V = 0 km/h.	
Activation of the BAS should introduce activation of the coach brake system.	yes	Movement of the train during BAS usage must be prevented
Minimum safety coefficient against yield strength	2.1	
The lift platform surface should be smooth and must have slip-resistant surface	yes	Slip resistance according to EN ISO 14122-2.
Easy removal of ice and snow must be possible	yes	
Gaps or holes in the platform area shall not accept a probe greater than:	15 mm diameter	
Illumination of the lift working zone	yes	
The warning devices should be fitted at edges that can come in contact with persons or injure passengers or personal.	yes	light / reflective stripes / reflective markings, visible at night also
Visual and audible warning signals during the lift movement must be activated	yes	
The operation control should be of type hold-to-run.	yes	Lift shall stop moving and remain motionless after the control is released.
Movement no more than 100mm for any part of the lift platform after release of the control is tolerable to slow lift down	yes	Mechanical drives with self-braking capability or with independent direct acting brakes, or hydraulic systems with normally closed valves etc. should be used.
Controls shall be designed to avoid unintentional lift actions.	yes	Recessed or covered buttons, two hand controls, etc.
One control position is recommended	yes	Conflicts of commands must be avoided
In any case of breakdown, it is acceptable that platform may decrease with controlled speed:	≤ 0,165 m / s	For example in hose or pipe failure by hydraulic systems or similar.
Safety devices shall preferably operate through active positive action.	yes	
A stop in overload protection should be present at overload more than	25%	
An emergency stop button within reach of the user should be present	yes	Release of the emergency stop button should only be possible by the personnel
Additional protecting measures such as obstacle detector, foot entrapment protection etc.	recommended	Although control of hold-to-run principle is used additional measures are recommended
During lift platform closing the risks of crushing or shearing of the arms or head must be avoided.	yes	Limitation of the closing force, security cut-off, etc.
Other technical details not covered in this table preferably should be based on:	TSI PRM, EN 1756-2, RVAR	

5. Outlook - Conclusions

Providing accessible rail transport to all passengers is nowadays a must. This is because of different national and European regulations but also because of ethical questions. That means every person must be able to use a public means of transportation. In light of this, the entrance to railway vehicles and the whole boarding process is a big challenge and causes huge difficulties.

In order to be able to provide accessible boarding to all passengers, the consortium tried to define the biggest gaps that must be closed.

For mid and long term thinking the results can be summarized as follows: Because level boarding is in the process of being or will be offered soon for all types of local, urban and suburban traffic; no systems are required. At this point, only horizontal gaps need to be bridged. Therefore, enough technical solutions already exist. In the rare case that level boarding is not possible, existing technical solutions can be used.

For all high floor vehicles with an entrance door width of at least 90cm, enough technical solutions such as different lifts exist. A new development is neither meaningful nor necessary.

The intensive investigations of the consortium led to the result that for the huge number of UIC-wagons which are running and will be running within the next decades all over Europe no vehicle based BAS yet exists. There are too many design limitations.

Due to the fact that UIC-wagons will still form the backbone in many European railway networks within the next decades; it is absolutely necessary to develop a BAS for this operation.

Due to the different limitations resulting from the vehicle construction, it is also necessary to make several compromises. But the developed compromise allows about 99% of all actual wheel chair users to board a UIC-coach. In combination with a good personnel service at the entrance, which is also recommended in this project, the UIC wagons can also become accessible for nearly all passengers.

References

Rüger, B.; Tauschitz, P.; Petutschnig, B. 2010. Boarding Assistance System Evaluation Criteria Report, deliverable 2.1, June 2010. EU-FP7-Project Public Transportation – Accessibility for all.

Rüger, B.; Tauschitz, P.; Petutschnig, B. 2010. Existing Boarding Assistance System Evaluation Matrix Report, deliverable 2.2, August 2010. EU-FP7-Project Public Transportation – Accessibility for all.

Simic, G.; Rüger, B.; Petutschnig, B.; Tauschitz, P.; Milkovic, D. 2010. Recommendations for Improving Boarding Assistance Systems; December 2010. EU-FP7-Project Public Transportation – Accessibility for all.

Rüger, B.; Tauschitz, P. 2012. D 4.4 – Vehicle based BAS prototype design and evaluation April 2012. EU-FP7-Project Public Transportation – Accessibility for all.

EFFICIENT RAIL INTERIORS - TYPICAL DESIGN ERRORS AND POSSIBILITIES FOR IMPROVEMENT

Bernhard Rüger[1]
[1] *Vienna University of Technology, Vienna, Austria*

Abstract: In order to be "competitive" as a railway, operating efficiency counts as an important imperative. In the context of railway carriage interior planning this is often made subordinate to other substantial aspects such as for example, expediency. This leads in practice to the opposite wished for result. Misunderstood operating efficiency concepts such as a maximal utilization of space for seating can in reality lead to a decline in operating efficiency, operational problems and in incidents to serious safety risks.

Keywords: passenger comfort, needs, expectations, passenger flow, utilization rate, optimization.

1. Introduction

The railway finds itself, especially in long-distance travel, in an area of tension between both of its competitors, road travel and air travel. People who travel by air have or at least see no alternative to air travel. This leads to an acceptance by air travellers of comfort constraints which arise due to economic pressures on the airlines. Airlines can afford to arrange the seats in the passenger cabin to achieve a maximum of seating. Since in airline travel reservations as well as the check-in of luggage are compulsory, all seats can therefore actually be used and sold.
For the railway such restrictions or drastic loss of comfort are not common and are therefore seldom implemented. Depending on travel duration and distance at least half of railway passengers could use the alternative of auto or air travel. Over 50% of travellers on ÖBB long-distance trains say that they have a driving license and have an auto available at any time. Also, because airline tickets are to some extent inexpensive, the cost argument regarding this mode of transportation is often eliminated. This in turn makes air travel more attractive.
The railway cannot afford to (and should not) ignore the demands and needs of travellers. In order to achieve the high proportion of railway travellers wished for in transport policy, which as a rule also actually contains economic benefits, the railway must bring into play the advantages which it has over other modes of transportation.
However, the tendency in recent years to equip vehicle interiors with the highest possible number of seats contradicts these considerations. This leads not only to a loss of comfort, which approximates the comfort level of air travel, but also in a number of ways constitutes serious operational problems. These problems are often not considered especially in the purchase of vehicles. The often applied evaluation criterion of the highest possible number of seats and thereby expected lower purchase- and operating costs per passenger is one-dimensional and therefore inadequate since it clearly contradicts reality in more ways than one. The consequences are elucidated in this paper.
Especially in long-distance train travel but also on many local routes particularly in the service of cruise ship ports and airports the volume of luggage is often underestimated and not taken seriously in sufficient measure as an influence factor on the criteria of station dwell time, achievable seat occupancy rate, comfort, customer satisfaction and ultimately safety.

2. Data basis

For nearly 15 years The Research Centre for Railway Engineering at the Technical University of Vienna has been intensively involved in cooperation with netwiss OG with questions on a scientific level related to the optimization potential of railway carriages. The core of all research and development projects as well as the resulting scientific work is the serious examination of the needs and wishes of travellers as well as with their problems and difficulties in using the train. A substantial contribution to the objectification of the findings is the data collected over a decade concerning passenger behaviour, which has been and will continue to be collected through observation. The goal thereby is to capture the real behaviour of passengers under different marginal conditions uninfluenced by possible personal sentiments which may affect the results of surveys. Surveys formed an additional basis for the scientific analysis.
Thus far, over ten years, data has been collected on the following areas:

- **Passenger flow analysis:** The boarding and deboarding of approx. 20,000 passengers in approx. 50 different boarding areas and vehicle types were observed. Through video analysis precisely to a tenth of a second it was ascertained how long on average a person needs for boarding and deboarding. Above all, in addition to knowledge about individual time requirements, crucial insight can be gained into the extent to which the entire vehicle design concept affects passenger flow,
- **Passenger surveys:** Approximately 40,000 passengers in just under 10 different countries were surveyed concerning their problems and difficulties as well as their needs and wishes in all phases of travel in a railway vehicle. This related to boarding as well as movement in the train, the search for seating, stowing of luggage and requirements during the trip itself.

[1] Corresponding author: bernhard.rueger@tuwien.ac.at

- **Passenger behaviour analyses:** The behaviour of approx. 200,000 passengers in more than 60 different vehicle types was analyzed with regard to choice of seats, storage of luggage and use of time. From the data, depending on the parameters of age, gender, occupancy rate in the vehicle and space design, information was accurately derived concerning which seats or seating areas were preferred, how and where luggage was stowed as well as the activities passengers performed,
- **Luggage data collection:** In combination with surveys, the exact anticipated luggage types and volumes per person, per vehicle or per train depending on travel purpose, age and gender as well as group size was determined through counting, exact measurements and weighing of several thousand pieces of luggage.

In terms of new vehicle design concepts the data provides exact conclusions on how the envisaged space design will be used, how the design will affect passenger behaviour regarding seat selection, storing of luggage and performance of activities, and what impact the behaviour will ultimately have on the parameters of passenger boarding and deboarding, proper stowage of luggage and actually achievable seat occupancy.

3. Luggage volume

Type, size, weight and number of particular pieces of luggage depend substantially on the parameters of travel purpose in combination with travel duration, age, gender and present group size of the travellers.
More than ten years of intensive observation shows that the volumes of individual pieces of luggage tend to be larger. This is due to an increase in comfort during transport particularly attributable to the fitting of luggage with rollers. For example, pieces of luggage which weigh 14 kilos and are meant to be carried feel as though they are the same weight as pieces of luggage which weigh 21 kilos but are equipped with two rollers. Fifteen years ago 50% of suitcases taken along on rail travel were not equipped with rollers and therefore had to be carried. Five years ago this percentage amounted to about 5%. In the meantime, nearly 100% of suitcases, so-called trolleys, are equipped with rollers.
In accordance with the comfort enhancement provided by rollers increasingly larger pieces of luggage are being manufactured and used by travellers. This has led not only to an increase in the size of individual pieces of luggage but also to an increase in weight. Meanwhile, the tendency can be seen in luggage manufacturers to equip more and more trolleys with four wheels. As a result, in many transport situations an additional increase in comfort has been achieved. The assumption is that these pieces of luggage will be felt to be even more comfortable and in weight comparison even lighter; therefore, in the near future a further increase in luggage volume and pack weight is to be expected.
Both the increase in weight as well as in size present the rail operator with corresponding challenges. Namely, in the case of boarding the train over steps as well as the frequently necessary lifting of luggage in stowing, the rollers provide no support and accordingly increase the difficulties for travellers.
The next figure presents the average luggage distribution per travel purpose (Plank, 2008).

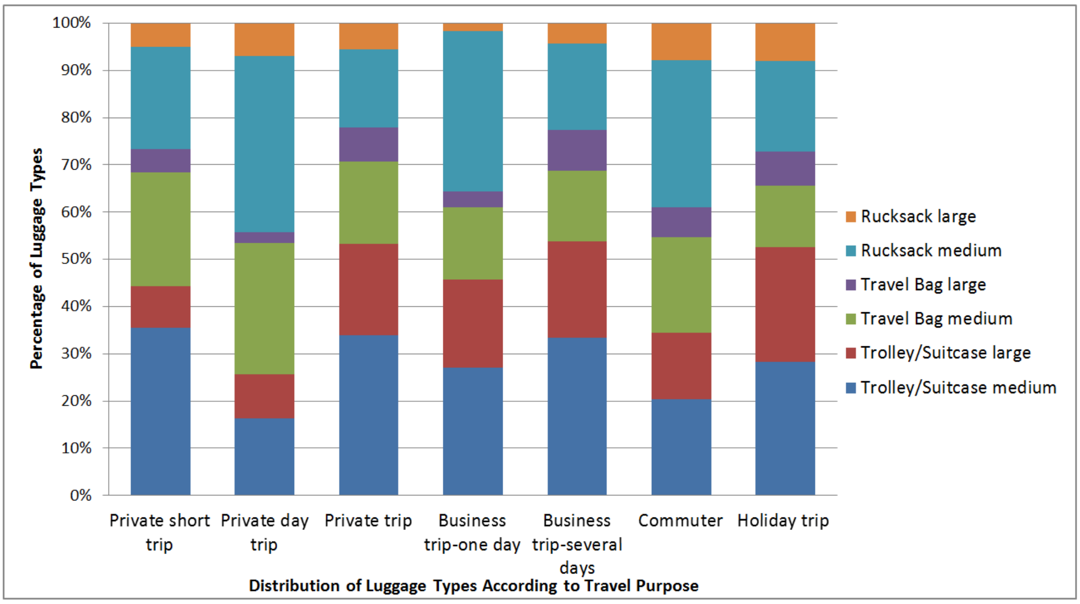


Fig. 1.
Average Luggage Distribution per Travel Purpose

In order to construct adequate and efficient luggage storage areas, as a first step, knowledge of luggage volume in terms of type, size, weight and number of pieces per person is important. With regard to an efficient overall interior design statements on this cannot and must not be generalized. It appears that there can also be a regionally specific difference in the accompanying luggage. In particular the total volume to be reckoned with for each carriage is highly dependent

on respective routes and their passenger or travel purpose mix. However, due to the existing amount of data very specific remarks can be made about this.
For example, in holiday travel on statistical average 50% of travel luggage pieces are medium and large trolleys (see Figure 1). At the same time it can be said that on average one piece of luggage per person is taken on holiday. On short trips on statistical average each traveller takes 0.8 pieces of luggage which are 35% medium and 10% large trolleys (see Figure 2). Relevant to necessary luggage accommodation is the most exact knowledge possible of the travel purpose mix which particular vehicles in their area of operation can expect. From this the actual expected average luggage volume per person and thus the corresponding total volume per vehicle can be determined.
The next figure presents the average luggage number per person and per travel purpose (Plank, 2008).

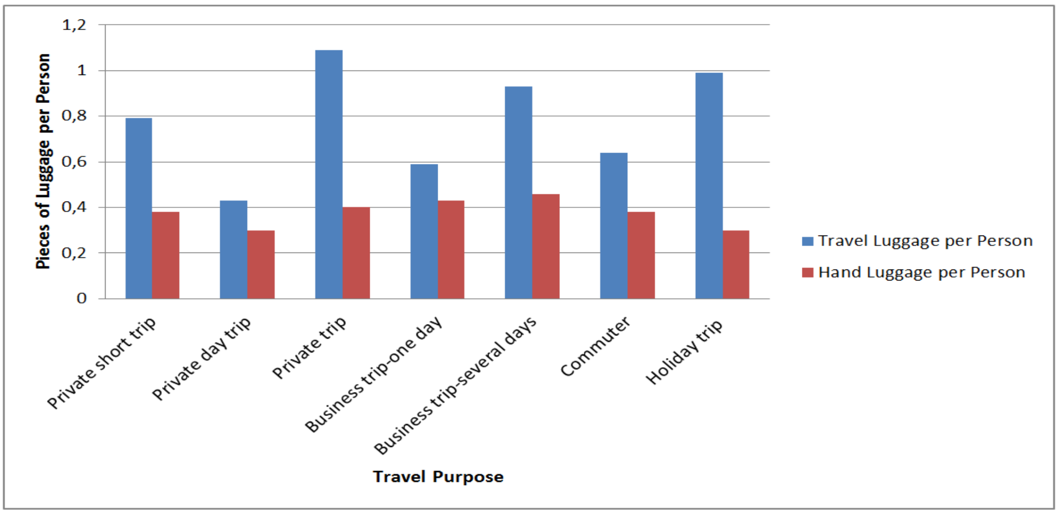


Fig. 2.
Average Luggage Number per Person per Travel Purpose

For air travellers who use the train for arrival an approx. 20% higher luggage volume is shown than for plain holiday train travel. This fact should be taken into account especially for all trains which eventually serve airports.
As an example of luggage volume, the average travel purpose distribution in Germany was used in a fictional carriage with 84 seats and a 100% occupancy, which led to the luggage volume represented in table 1.
The next table shows an example for the luggage distribution for one wagon (Rüger et al., 2010).

Table 1
Fictional Example: Luggage volume for an average travel purpose distribution in Germany with 84 people per carriage

Luggage type	Dimensions (cm)	Number with 84 People
Trolley large	approx. 80x50x35	13
Trolley medium	up to 70x50x30	23
Travel bag/Rucksack large	approx. 90x40x35	9
Travel bag/Rucksack medium	up to 70x35x35	29
Hand luggage	up to 55x40x25	32

On average travel days an average of 36 medium and large trolleys and 38 medium and large rucksacks or travel bags were stowed. With regard to luggage accommodation the total volume of luggage must subsequently be superimposed on the wished for or actual passenger behaviour concerning the accommodation. For example, to believe that the luggage volume can be accommodated in overhead racks is a fatal mistake. Even if the calculated luggage volume could be stored in overhead racks the majority of travellers would not use the overhead racks. This means in practice much of the luggage would be stowed disruptively (see below).

4. Luggage Accommodation

4.1. Passenger Behaviour

Regarding luggage accommodation there are two fundamental principles. Travellers do not want to have to lift their luggage; and for security reasons they want to have visual contact with their luggage at all times. If these two criteria are not sufficiently taken into account from the very beginning of planning, inefficient and in an "incident" quite dangerous conditions in the vehicles can be expected.

For 88% of passengers visual contact to their luggage is important or very important. This means that luggage must be able to be stowed in close proximity to the traveller. If there is no adequate possibility for this, and the luggage must be stowed at a greater distance, such as in luggage racks near the entrance, for most travellers this results in a corresponding uneasiness and loss of comfort. However, from an operational viewpoint the risk is even greater from luggage which due to a lack of visual contact has been stowed disruptively. Seventy-five percent of travellers indicate explicitly that they are prepared to stow their luggage disruptively in order to meet the need for visual contact.
As a result, luggage is placed on or in front of seats or in aisle areas. This leads to an increase in unusable seats and obstructions to passenger flow.
The second important criterion with regard to planning appropriate luggage racks is the willingness to lift luggage. For example, only 20% of travellers are prepared to lift heavy luggage into the overhead rack; over 50% are under no circumstances ready to do such lifting. With medium sized luggage at least 50% are prepared to lift it into the overhead rack. With regard to luggage racks, at least 50% of travellers are prepared to lift heavy luggage up to waist level (see Figure 3). These specific values make it clear that it is pointless to provide overhead racks with no exception or alternative. Also, the existing number of luggage racks must be adequately dimensioned!
The next figure presents the readiness to lift luggage (Plank, 2008).

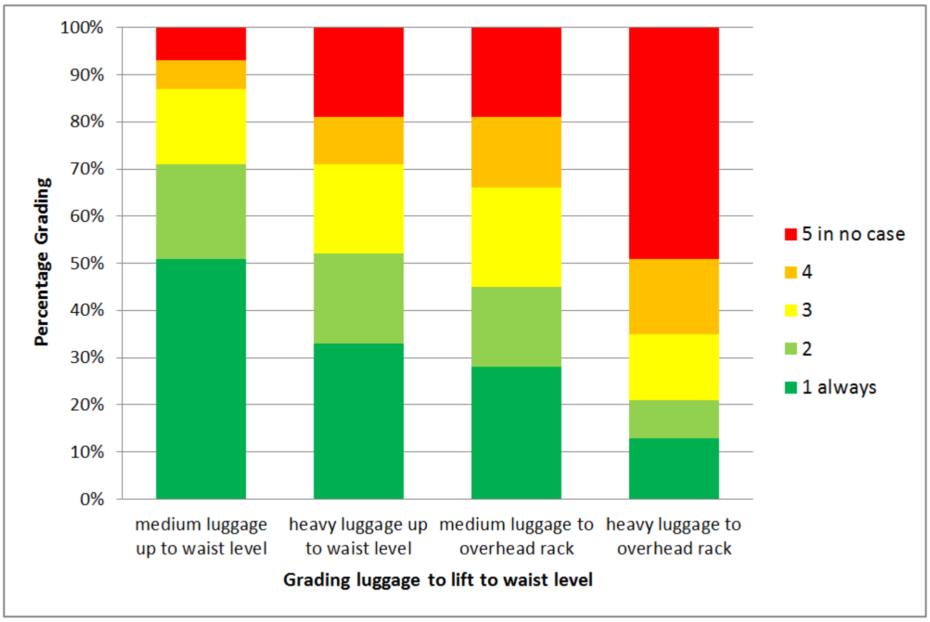


Fig. 3.
Readiness to Lift Luggage

The sampled readiness regarding luggage accommodation has been confirmed by extensive objective observations. Although in some cases up to 50% of the overhead racks are not used, a variety of pieces of luggage are placed on the floor, in front of seats, in the aisle or on seats.
At lower occupancy rates of up to 35%, thirty percent of medium and large trolleys are placed on or in front of seats or in the aisle. Even at high occupancy rates of over 70%, by which making seats free can be expected, up to 20% of large and medium sized trolleys are placed in these positions. With rucksacks and travel bags nearly the same behaviour has been observed.

4.2. Possibilities for Accommodation

The basic possibilities for luggage accommodation are: overhead racks, luggage racks and spaces between the seat backrests. In part, areas under the seats can also be used. However, as a rule these areas can be used only for those pieces of luggage which fall under the category of hand luggage.
In order to design luggage storage space so that even with a very high occupancy rate all luggage can be properly accommodated, the following principles must be observed:

- Above mentioned principles "not lifting" and "visual contact",
- Determination of the actual luggage volume,
- Reliable knowledge of the shape of the luggage.

In order to efficiently design the most popular storage spaces between the seats and in the luggage racks, knowledge of the shape, size and volume of the luggage is by all means essential. Experience shows that luggage racks which are only a few centimetres, often only 5 cm to 10 cm too narrowly dimensioned, or whose shelf heights are too high or too low, can hold up to 50% less luggage than suitably dimensioned shelves!

The same applies to the space behind or between the seat backrests. Here 10 cm to 15 cm of too little usable space can lead to 70% less storage space.
In addition to the appropriate sizing of luggage racks and seat spacing, it is also important to ensure a well considered distribution of luggage storage possibilities in the vehicle. These must be distributed as evenly as possible over the vehicle to allow good visual contact to luggage from each seat and not impair the flow of passengers.

5. Consequences of unsuitable luggage accommodation possibilities

If the important basic principles of luggage storage space design are not respected, two serious operational consequences can be expected. The passenger boarding and deboarding time in stations will be prolonged and the actual available occupancy rate will decline up to 80%.

5.1. Passenger boarding and deboarding time

There are many factors which affect passenger boarding and deboarding time. These include passenger related factors which manufacturers and operators have no control over. These factors include age, gender, accompanying luggage and any kind of mobility limitation.
However, the vehicle-side factors are important. On one hand, by correct planning the passenger-side factors can be correspondingly reduced; on the other hand, by improper planning these can be exacerbated. These factors include for example, the entry height and door width, potentially any existing level entrances, location and number of entrances, the suitability of entrance spaces as collection areas, any restrictions to passenger flow and the overall design of the vehicle interior.
From the perspective of passenger boarding and deboarding time the difference between the best and the worst vehicles currently in use is at a ratio of 1:4. This means in concrete terms that with an assumed passenger boarding and deboarding time of one minute in the best case, the time for the same number of passengers in the worst case can be up to four minutes! It should be noted here that with some exceptions younger generation vehicles which are currently in operation tend to produce higher values.
The next figure presents the average the required boarding and deboarding time in different interior concepts (Tuna, 2008).

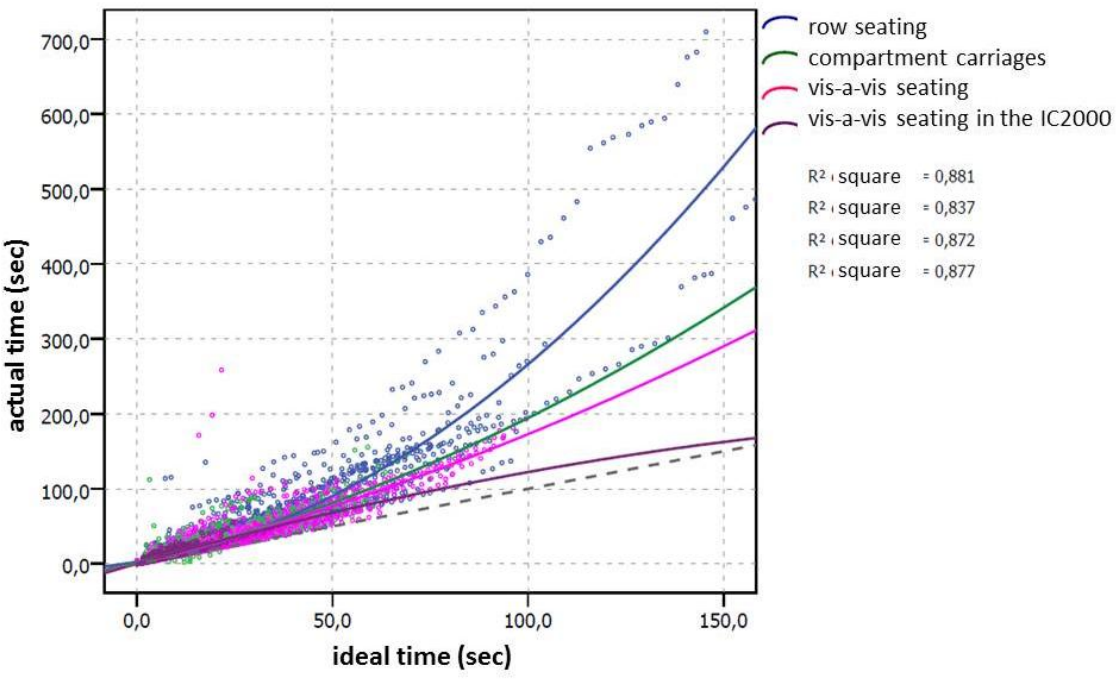


Fig. 4.
Time required for the boarding and deboarding process in different interior designs

The influence of interior design between the best and worst case already produces an affect with a ratio of 1:2 (see Figure 4). This means for example, in the best case at a high rate of passenger exchange in conventional vehicle constructions, a passenger boarding and deboarding time of two minutes can be achieved. Whereas, in the worst case it requires four minutes.
In Figure 4 fundamental concepts are presented; in such a way whereby in this example in row seating practically only overhead racks are available and in vis-a-vis seating luggage can be well stowed between the seat backrests. There is similar data from approximately ten basic vehicle interior categories. All findings show the clear correlation between

time demand and luggage storage. The more suitable the design of luggage storage areas, the less time is needed for boarding and deboarding.

5.2. Occupancy rate

From an operational point of view, the second relevant effect of well planned or vice versa insufficiently thought out luggage storage areas, is the actual occupancy rate.
In long-distance traffic the only significant occupancy rate is the seat occupancy rate. With unsuitable and insufficiently designed luggage storage possibilities, even this can decline noticeably. In conventional passenger carriages with a length over buffers of 26.4 meters, a maximum of 80 seats for standard days and 78 seats for travel days are provided (see Figure 5). This number is achieved if the remaining areas are used in suitable form for luggage storage. If this is the case, up to 100% of the seats can be occupied. If there are more seats over these limits, it is at the expense of customer-oriented luggage accommodation; and the actual number of available seats as well as the occupancy rate sink drastically. Previous studies by the Research Centre for Railway Engineering at the Technical University of Vienna show that the average achievable occupancy rate in comparable vehicles with 88 seats is only about 80%. This means that on average only 70 of the 88 installed seats can be used (see Figure 5)!
The reason for the sharp decline in occupancy is that there is not enough luggage accommodation capacity available and the existing areas are frequently unsuitably designed. This leads to the fact that part of the luggage is stored not only in the aisle but also on and in front of the seats.
The next figure presents the maximum possible number of available seats (Plank).

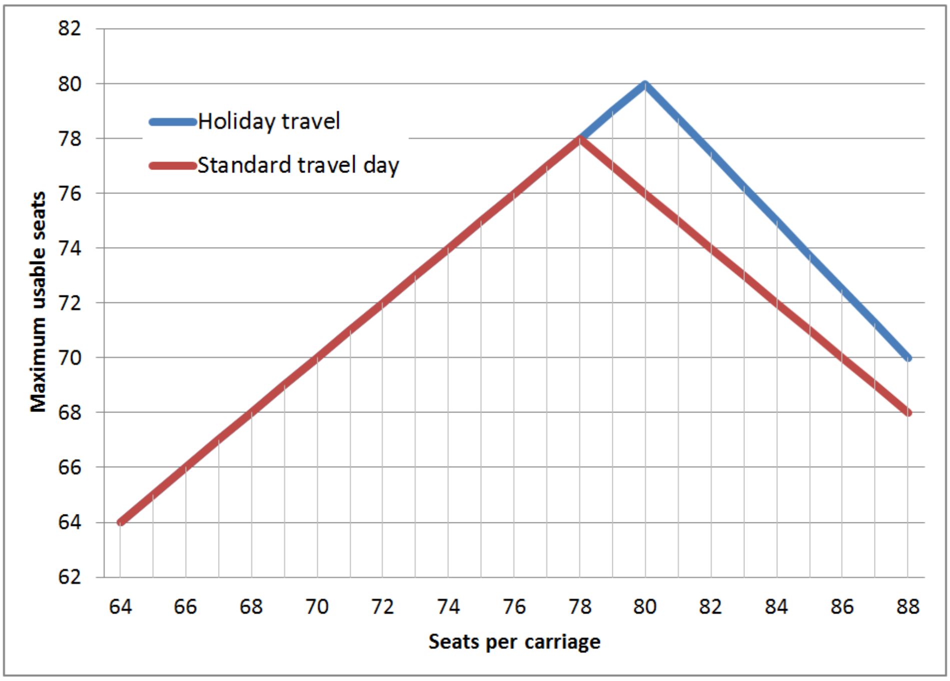


Fig. 5.
Maximum possible number of seats in passenger carriages with a length of 26.4 meters over buffers

5.3. Operating efficiency

The consequences of falsely planned luggage storage possibilities presented so far ultimately have significant operating efficiency impacts. The hope or goal to also be more efficient through a greater number of seats is transformed as a general rule into the opposite. Under the premise that the goal is to want to take advantage of the highest number of available seats, the following circumstances always prevail:

- **Delays:** Vehicle interiors following the idea of seat maximization inevitably lead to long station stop times. With a high passenger exchange, four to six minutes per station are the result. Whereas, ideally designed vehicles require only one to one and a half minutes. This fact in the case of a close sequence of stations leads to corresponding delays.
- **Declining operating quality:** When they cannot be made up for, the aforementioned delays lead to a decline in operating quality. This is especially important if delays are carried over to connecting or opposite trains, or if the results are missed connections.
- **Higher energy consumption:** If it is at all possible to make up for the delays, it is only possible by constant use of maximum line speed, which means a significant additional energy consumption especially at a high rate of speed.

- Lower occupancy rate: There are seats installed which in practice are not available. At the same time the achievable seat occupancy rate declines up to 20%!
- **Declining passenger satisfaction:** The declining seat occupancy rate causes a correspondingly high number of standing passengers, which accordingly reduces passenger satisfaction. Comfort is significantly reduced by the in part "chaotic" conditions in "overcrowded" vehicles. For nearly 18% of travellers high occupancy together with the already mentioned associated effects means a high stress factor!

5.4. Safety

The most important criterion which is often overlooked in insufficiently estimated operating efficiency considerations is safety. If in an emergency a train has to be evacuated, a large number of seats at a high occupancy rate in combination with the aforementioned effects presents a high safety risk. In air transportation a maximum evacuation time of 90 seconds must be proven before the certification of an aircraft.2 In railway transportation there are no such known provisions. However, it is understood that in most vehicles this time cannot be met. In a fully occupied carriage with 88 seats, the absolute exit time of all passengers under ideal conditions (no luggage during the exiting process, no backup because of crowding at the entrance door, only two steps) with the best carriage designs approx. 120 seconds is required and with the worst constructions, approx. 160 seconds.

In an incident, rising panic must be considered in which case an orderly exiting process cannot be expected. Above all, in this case improperly stowed luggage would lead to a corresponding safety risk! For this reason alone it must be ensured that for every installed seat there is also a suitable luggage storage space.

6. Fundamental planning errors

From past experience, both on the part of the purchaser as well as on the part of the manufacturer, fundamental errors which lead to the inefficient conditions described above can be identified in the planning and ordering process.

Error 1: Volume calculation: Every cuboid-like object has a volume and also three definite dimensions. As a rule In tender documents there is only information on the total volume required for luggage accommodation. For cuboids the volume is known as the product of width, length and height. This means that an often called for volume of approx. 0.125m³ per passenger can either correspond to the dimensions of a midsized trolley with dimensions of 50x70x35 cm, or at the same time, a trolley with dimensions of 1x4160x30 cm! Accordingly, it is also common practice to multiply every small cross-sectional area by the available depth and to sum the resulting volumes to a total volume! As a rule, in practice a maximum of 50% of the calculated volumes are available. It is therefore necessary to have precise knowledge of the statistical distribution, shape and dimensions of the luggage!

Error 2: Disregard of passenger behaviour: If the principles of "not lifting" and "visual contact" with regard to luggage storage construction are disregarded, the planned storage areas will be only in part accepted by the passengers. In practice this leads to the condition that up to 50% of all storage areas remain unused and yet a larger amount of luggage is stored disruptively.

Error 3: False awareness of luggage volume: The actual luggage volume has to be calculated for each route and expected passenger or travel purpose mix. Frequently blanket assumptions are made, or days are taken as a basis for calculation on which only a below average luggage volume can be expected.

Error 4: False dimensioning: Meanwhile, luggage accommodation is increasingly being taken into account in vehicles with regard to the installation of luggage racks and the space between the seat backrests. However, here it must be noted that the dimensions of luggage racks are often oriented to seat spacing resulting in very inefficient dimensions. The same can be observed in the spaces between the seat backrests. When dimensioning the respective storage areas it is advantageous to take into account the forms and dimensions of the luggage as well as the storage behaviour of passengers. Seat spacing and luggage racks are often dimensioned a few centimetres to small, which can lead to an actual storage loss of 50% or more.

Error 5: False evaluation criteria for orders: In vehicle orders it can often be observed that evaluation criteria are applied which are not logically understandable. A popular evaluation criterion in tenders is to define the minimum number of seats. Usually this involves specifications which can be classified as a psychological perception; and thus, they often jump to increments of 100. If for example in the tender as a fictitious number it is predetermined that a train must have 500 seats, then the hands of the manufacturer are already bound in the tender phase; and from the outset actually efficient solutions are not possible. These figures are usually based on a previously calculated maximum number per vehicle and thereby disregard reality. With the fictitious example mentioned it can be expected that a maximum number of 450 seats will actually be available in the train. Thus, it would be much more efficient to make no such requirement, but rather to allow the manufacturers to search for efficient overall solutions. With appropriate solutions it can be expected that vehicle design concepts can be found which in the example mentioned offer approx. 470 seats. Seats, which in the end can actually be used!

[2] http://de.wikipedia.org/wiki/Evakuierungssimulation

7. Conclusion

Fifteen years of research and development as well as participation in numerous vehicle plans make it clear that at all times with vehicle development and orders an overall optimum for vehicle interiors should be sought. Many negative examples make clear that the exclusive pursuit of a maximum number of seats can in practice lead to inefficient and dangerous situations. In particular, luggage storage possibilities must be precisely and thoughtfully planned in order to contribute to efficient overall systems. Experience further shows that it is very critical to lay aside blanket assumptions about design. Each vehicle must be assessed individually in terms of attainable overall efficiency which ultimately leads to an actual maximum seating occupancy.

Requirements for luggage storage must be thoughtfully formulated in the tender. Furthermore, in order achieve the greatest possible degree of efficiency, where and which luggage storage areas can be installed must be precisely considered in the beginning phase of vehicle planning. Later changes are usually achieved only with great difficulty or with little effect.

Fortunately, in recent times one can discern an awareness regarding these problems. Numerous recent projects confirm that both on the part of the operators as well as the manufacturers, interest in and willingness to develop efficient overall systems have emerged; and that some efficient overall solutions can be developed with negligible additional cost.

References

Tuna, D. 2008. *Passenger Exchange in Passenger Transportation*. TU-Vienna, Institute for Railway Engineering, Transport Economics and Cable Railways, Vienna, Austria.

Cis, P. 2009. Occupancy Rate of Railway Carriages Depending on Individual Passenger Behaviour. Diploma Thesis, TU-Vienna, Institute for Railway Engineering, Transport Economics and Cable Railways, Vienna, Austria.

Plank, V. 2008. Dimensioning of Luggage Storage Areas in Passenger Trains. Diploma Thesis, TU-Vienna, Institute for Railway Engineering, Transport Economics and Cable Railways, Vienna, Austria.

Rüger, B.; Tauschitz, P.; Petutschnig, B. 2010. Boarding Assistance System Evaluation Criteria Report"; Report for European Commission; Report-No. Deliverable D2.1.

WHERE DO CYCLISTS RUN RED LIGHTS? AN INVESTIGATION INTO INFRASTRUCTURAL CIRCUMSTANCES

Tadej Brezina[1], Bernd Hildebrandt[2]
[1] *Vienna University of Technology, Institute of Transportation, Research Center of Transport Planning and Traffic Engineering, Vienna, Austria*
[2] *Austrian Transport Safety Board KfV, Department of Traffic Engineering, Vienna, Austria*

Abstract: Urban cyclists frequently run red traffic lights. This picture is commonly painted by media and public opinion. Our study aims at checking infrastructural influences on such alleged behaviour in order to brighten the view in this controversial public debate. We start by analysing accidents comprising cyclists running red lights. Based on Viennese intersections with an accumulation of red light infringements, the stop-willingness at red lights is studied in-situ. For traffic technological measurements, a total of 23 promising intersections is clustered by physical parameters in 5 settings. The parameters include classified cyclists counts, crossing length, number of crossed lanes, green and red time and compliance with the maximum waiting time according to the Austrian design guidelines. In addition test rides were carried out to estimate the proportion of waiting times to trip times and the traffic light density. The test rides revealed: average distance between traffic lights is 231 m and waiting time is about one quarter (25.9 %) of trip time. 19.2 % of 3,141 observed cyclists run the red light without stopping, while 11.5 % stopped before then running the red light. Therein the proportion of men was higher than with women (28.9 vs. 23.9 %). Cyclists disobeyed red lights about six times more often with demand button traffic lights than with regular traffic lights. As soon as only a single pedestrian crossing lay ahead, infringements happened 4.5 times more frequently than in other circumstances. In comparison to similar traffic volumes cyclists are awarded about 30 % less green time than motorized vehicles. Due to repeated de- and acceleration, the high traffic light density and proportion of waiting times have an obstructive impact on attractiveness for cyclists. Based on our findings we recommend measures to improve urban intersection design to facilitate ecologically attentive transport better.

Keywords: urban cycling, red traffic lights, cycling infrastructure, cycling safety, behaviour.

1. Introduction

A significant number of international studies are dealing with the subject of red light infringements which underlines its high relevance. The share of cyclists running red lights varies considerably. Ortlepp et al. (2008) as well as Johnson et al. (2011) both report that about 7 % of cyclists ran red lights. A range of 27.4 % in Netherlands to 30 % in the USA was reported by van der Meel (2013) and Monsere et al. (2012). The highest share is reported from China, up to 50 % (Wu, C., et al. 2012). Red light riding was found to be the second most frequent infringement among cyclists (Alrutz, D., et al. 2009). However, while 99.6 % of cyclists are aware of the correct behaviour at red lights, 45 % admitted to abide by these rules (Alrutz, D., et al. 2009). Van der Meel (2013) reports 27.4 % of cyclists infringing red lights – depending on location and layout. Alrutz et al. (2009), Johnson et al. (2011) and Van der Meel (2013) both find that males and young aged persons dominate in this behaviour over females and adults and senior citizens. All three studies also investigated infrastructural impacts on red light behaviour. The trends of their findings are summarized in Table 1.

Table 1
Infrastructural parameters' impact on red light riding behaviour from existing literature

Infrastructure parameter	Impact on red light riding
Traffic volume	Lower red light cycling share for higher traffic volumes
Duration of green phase	Lower red light cycling share for longer green phase
Duration of red phase	Higher red light cycling share for longer red phase
Crossing distance	Lower red light cycling share for longer crossing distance
Riding direction	Higher red light cycling share for right turns than for straight ahead rides
Sighting distance	Lower red light cycling share for limited sighting distances
Centre island	Higher red light cycling share when centre island is present
Velocity of lateral traffic	Lower red light cycling share for higher velocity of lateral traffic
Composition of lateral traffic	Lower red light cycling share for higher share of trucks and busses

Between 2000 and 2003 about 18 % of lethally crashed cyclists were involved in red light infringement crash (Lutschounig, S. and Robatsch, K. 2005). Based on Vienna's total traffic accident database, Fig. 1 and Fig. 2 show distributions of red light infringement casualties of cyclists related to day time, week and month. Along with the general timeline of cycling volume, a definite peak can be found between 3 and 6 pm, while night hours result in very little crashes. During the week, most incidents take place from Monday to Thursday. During the course of the year, the months from May to August show the highest numbers and incidents in fall are more frequent than in spring.

[1] Corresponding author: tadej.brezina@ivv.tuwien.ac.at

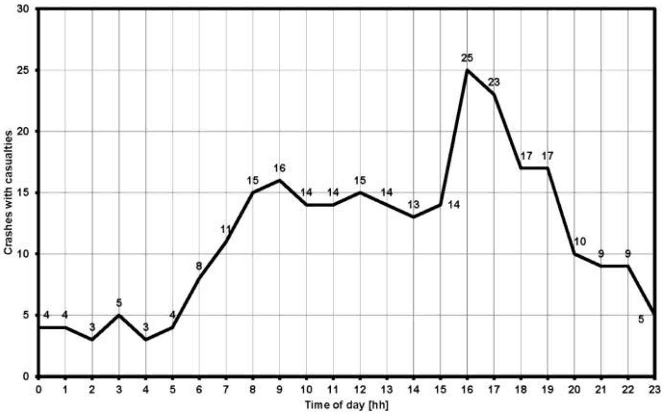


Fig. 1.
Timeline of cyclists' red light infringement crashes with casualties in Vienna from 2004 to 2013 (n=272)

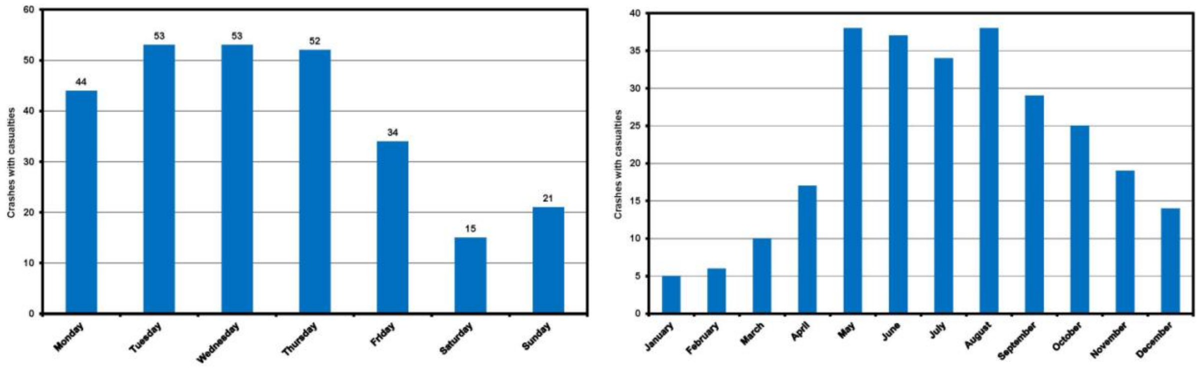


Fig. 2.
Cyclists' crashes with casualties in Vienna from 2004 to 2013 by days of week (left) and by month (right) (n=272)

In principle drivers for red light infringement can be grouped in personal, non-influenceable critera and influenceable traffic engineering criteria. Our task of research was to focus on the latter and find the impact of transport infrastructure design features on the frequency of cyclists infringing red lights. The second section delimits the materials and methods that are used in field study and analysis. Section three shows the results of analysis and the final section provides conclusions from the survey to be used for the improvement of intersection design.

2. Materials and Methods

Two survey methods are used:

- Seven test rides on a bicycle. These rides criss-crossed densely built-up central Vienna were 3.06 to 6.58 km long and took between 14 and 30 minutes to ride while traversing 14 to 32 traffic lights,
- In-situ, stationary measurements of cyclists' behaviour at 18 pre-selected traffic lights clustered in 5 settings in Vienna. The sites are located in densely built-up central Vienna within or closely outside of the second ring road (Table 1).

The choice of intersections for the in-situ measurements is based on intersection typology and layout and on the analysis of disaggregated Viennese crash data (see Table 2). After a brief pre-survey, three sites per setting were chosen to be studied in depth.

Table 2
Clustering of 23 survey sites

Setting	Number of pre-selected sites	Number of surveyed sites	Number of observations	Sites located in Vienna's districts
1 – Cycling path crosses one car lane	5	3	668	1, 4, 15
2 – Cycling path crosses more than one car lane	5	3	943	1, 4
3 – Push-button traffic light for cyclists	5	3	337	1, 4, 20
4 – Cycling path crosses pedestrian path	5	3	609	2, 7
5 – Cumulation point of cycling crashes after red light violation	3	3	584	8, 9, 16

The in-situ measurements took place for 2 hours per site during weekdays and included the behaviour of 3,141 cyclist in total, mostly males in the age class of 25 to 65 years (Fig. 3. left). In comparison to Vienna's total distribution (Fig. 3. right), male riders aged 25-65 are over-represented in our sample. Jellinek et al. (2013) reported an age distribution among cyclists as follows: 5 % children younger than 14 years, 13 % of youngsters between 15 and 24 years, 68 % of adults between 25 and 65 and finally 14 % of senior citizens beyond the age of 68.

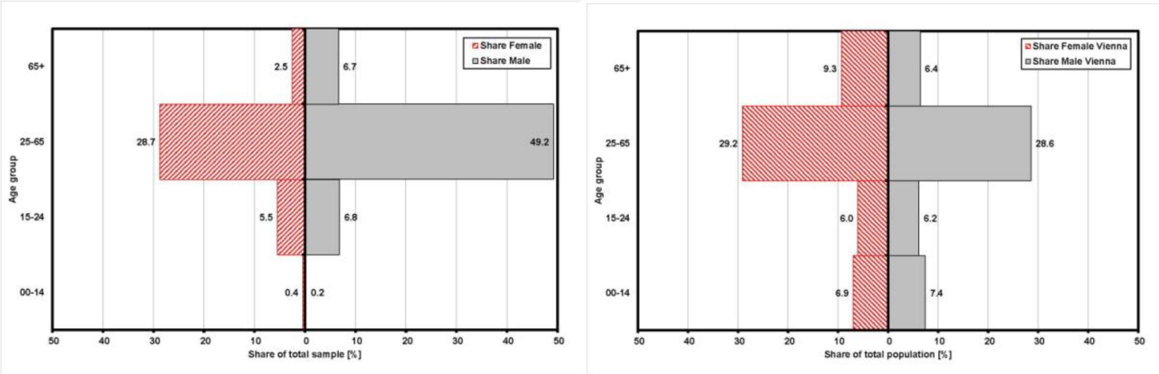


Fig. 3.
Age distribution by sex of observed cyclists (n=3,141) (left) and of Vienna's total population (n=1,840.226) at January 1st 2016 (right)

3. Results

The seven test trips resulted on average in:

- 4.3 traffic lights per trip km.
- 16 seconds waiting time per intersection.
- 71 seconds waiting time per trip km.
- 25.9 % as ratio of waiting time to total trip time.
- 231 m average distance between traffic lights.

Six types of cyclists where distinguished by studying red light behaviour:

- Red riders in middle red-phase who do not wait before riding, i.e. crossing without hesitation
- Red riders in middle red-phase who wait before riding, i.e. crossing after a full stop
- Late riders in early red-phase, crossing shortly after the end of the green phase
- Early riders in late red-phase, crossing shortly before the beginning of the green phase
- Green riders who wait at red and wait for green before riding.
- Green riders who arrive at green and do not wait before riding.

For all survey sites the types of observed behaviour is shown in Fig. 4. 1,124 of 3,141 cyclists (35.8 %) ride when their light is still showing red. This red-riding rate varies strongly by location from around 11 % up to 80 %. Compared to the international numbers given in the introduction, Vienna is among the leading group. However, this value is not representative for all of Vienna's intersections as it was the task to find and survey some of the most problematic sites. More than half of red riders passed without stopping. 35.2 % of riders waited in front of the red light to turn green before continuing to ride. More than half of the red riders crossed without stopping.

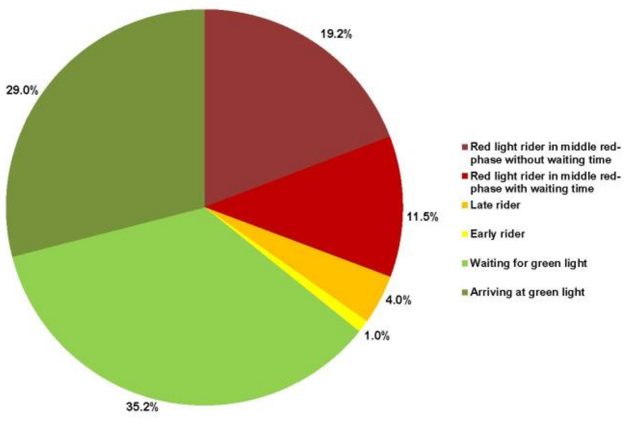


Fig. 4.
Red and green light riders for all survey sites by type of behaviour (n=3,141)

19.2 % of 3.141 ran red lights without stopping, while 11.5 % stopped briefly before running the red light. Therein the proportion of men was higher than with women (28.9 vs. 23.9 %). Cyclists disobeyed red lights about six times more often with demand button traffic lights than with regular traffic lights. If only a pedestrian crossing lay ahead, infringements happened 4.5 times more frequently than in other circumstances. The distinction by sex shows a male prevalence by a factor of 1.2 over female riders. Youngsters ran the red light 1.6 times more frequently than adults.
Distinguishing rider types by surveyed settings reveals a more diverse picture (Fig. 5). While all other settings show a disobedience rate of about 30 %, setting three "Push-button traffic light for cyclists" reveals about 70 % of riders running red lights. On the other hand sites from setting five, the culmination points of bicycle crashes, showed the least infringement rates (18.5 %). The share of green riders strongly depends on duration of green and red phases and the coordination of the traffic light with its adjacent traffic lights. At 4 out of 15 surveyed locations, disobedience rates reached more than 50 %.

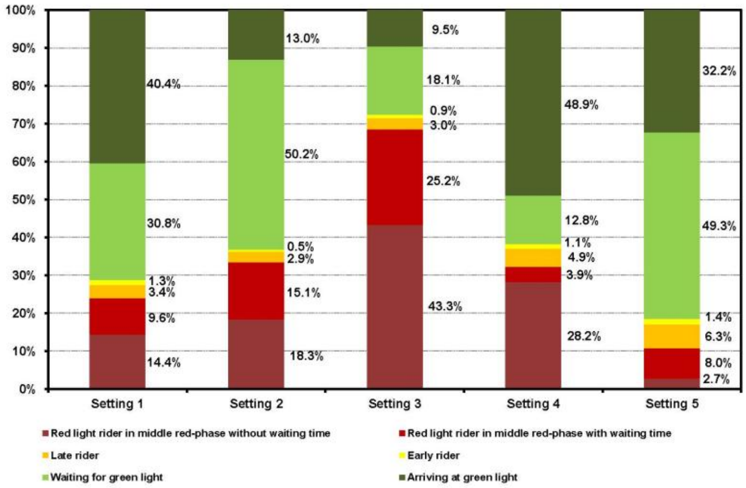


Fig. 5.
Red and green light rider behaviour by setting (n=3,141)

By excluding riders that arrive at green from the total sample, the willingness to stop can be derived. In this case, settings three and four show the lowest willingness to stop: 20.0 and 25.1 %. The three remaining settings feature willingness shares bigger than 50 %: from 51.8 to 72.7 %. Settings three and four are sites with Push-button traffic lights for cyclists and intersections where cycling paths cross only pedestrian paths.
Where the red phase lasted 60 seconds or longer, cyclists run the red light 2.7 times more often than in sites with shorter periods. At push-button traffic lights (setting 3) the disobedience rate was 6 times higher and at intersections with only a pedestrian walkway it was 4.5 times higher than in the remaining settings.
Finally we analysed the sites' impact on relation between share of cyclists arriving at green and the ratio of green to red phase time (Fig. 6). In addition we plotted the relation of average waiting time to green time coefficient over the share of red riders (Fig. 7). These diagrams show:

- That cyclists tend to arrive at green lights more frequently when the green time's share increases,
- That cyclists tend to infringe red lights more often when average waiting time increases over green-time.

Average waiting time is better suited for explanatory means than red phase duration as it implies the coordination with preceding traffic lights.

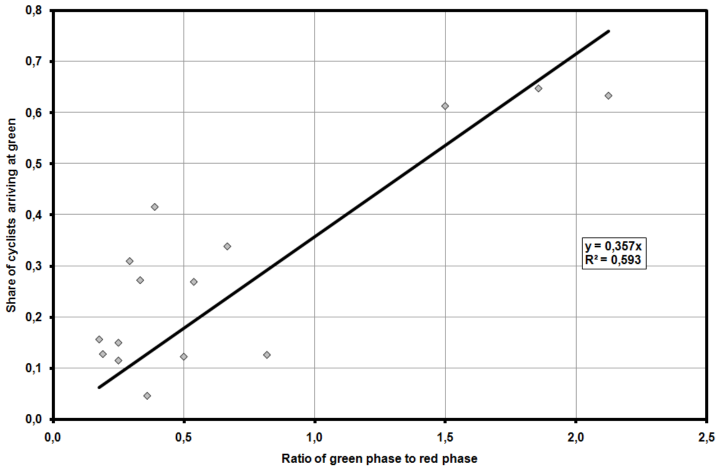


Fig. 6.
Green to red time ratio over green riders without waiting time (n=15)

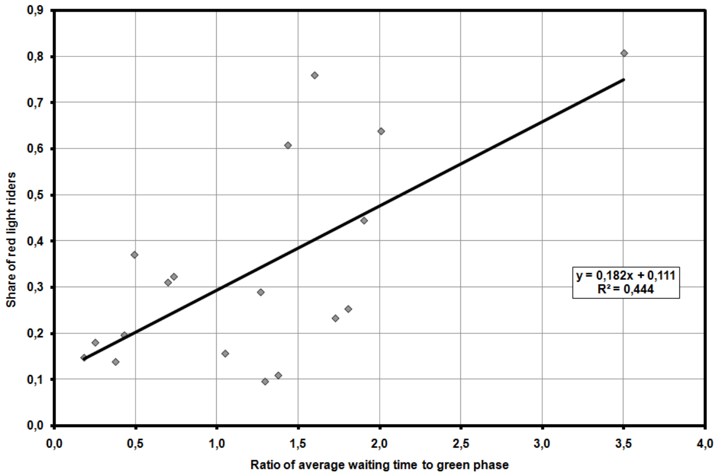


Fig. 7.
Average waiting time to red time ratio over red riders (n=18)

4. Discussion and Conclusion

The high density of traffic lights and the long waiting times considerably reduce the potential for cycling in Vienna. Under the premise of travel time stability, waiting times in extent of 25 % of total trip time reduce possible trip lengths by about one quarter. In addition, recurring bicycle de- and acceleration due to the high traffic light density of 4.3 traffic lights per km increases rider energy expenditure.
Applied to car traffic only, ease of traffic flow is considered the highest priority. For the same amount of vehicle throughput, this reduces green time for cyclists by 70 %. The crucial advantage of higher throughput of cyclists per unit of width is thus forfeited. As 14 out of 23 traffic lights showed red phases longer than 40 seconds, a large portion of studied traffic lights can be considered as cyclist-unfriendly. A low acceptance (inverse figure of disobedience) asks to be interpreted as indicator of low bicycle friendliness. Settings three and four with their significantly high disobedience rates teach us that such designs shall be avoided.
Only 1 out of 1,124 observed red cyclists had a conflict situation with a car driver. Red cyclists cautiously observed crossing traffic regarding approaching vehicles and their time gaps before infringing the red light.
The limitations of the study at hand suggest in-depth work to implement improvements and perform the following measurements:

- Time gaps between crossing vehicles,
- Velocities of crossing vehicles,
- Sizes of arriving cyclist groups,
- Distinction between cyclists riding straight on and those turning right into the crossing traffic.

Based on our findings we suggest measures to improve urban intersections insofar that infrastructure design supports ecologically attentive transport. Our recommendations are:

- Reduce density of traffic lights in general,
- Reduce average waiting times to below 40 seconds,
- Avoid waiting times of 60 seconds or longer,
- Give cyclists traffic lights of their own instead of combining the with a pedestrian lights,
- Avoid push-button traffic lights,
- Introduce coordinated traffic lights for cyclists – “green wave”,
- Study and then introduce right turn on red for cyclists, as it is already common in many other countries (Netherlands, France, Belgium or Switzerland).

Acknowledgements

Thank you to Eleonora Balaoura, Manuela Winder and Helmut Lemmerer for proof-reading.

References

Alrutz, D.; Bohle, W.; Müller, H.; Prahlow, H.; Hacke, U.; Lohmann, G. 2009. *Unfallrisiko und Regelakzeptanz von Radfahrern*; BAST; Bergisch Gladbach, Germany.

Jellinek, R.; Hildebrandt, B.; Pfaffenbichler, P.C.; Lemmerer, H. 2013. *MERKUR - Auswirkungen der Entwicklung des Marktes für E-Fahrräder auf Risiken, Konflikte und Unfälle auf Radinfrastrukturen*, Österreichischer Verkehrssicherheitsfonds, Wien, Austria.

Johnson, M.; Newstead, S.; Charlton, J.; Oxley, J. 2011. Riding through red lights: The rate, characteristics and risk factors of non-compliant urban commuter cyclists, *Accident Analysis & Prevention*, 43(1): 323-328.

Lutschounig, S.; Robatsch, K. 2005. Rotlichtüberfahrer, *Zeitschrift für Verkehrsrecht*; 41(4): 141-144.

Monsere, C.; Figliozzi, M.; Thompson, S. 2012. *Operational guidance for bicycle-specific traffic signals in the United States: A review - Interim Report #1*; Oregon Department of Transportation and Federal Highway Administration; Portland, U.S.A.

Ortlepp, J.; Neumann, V.; Utzmann, I. 2008. *Verbesserung der Verkehrssicherheit in Münster - Schlussbericht*; Gesamtverband der Deutschen Versicherungswirtschaft e.V, Berlin, Germany.

Van der Meel, E.M. 2013. *Red light running by Cyclists: Which factors influence the red light running by cyclists?*. Master's Thesis. Civil Engineering and Geosciences, TU Delft; Delft, Netherlands.

Wu, C.; Yao, L.; Zhang, K. 2012. The red-light running behavior of electric bike riders and cyclists at urban intersections in China: An observational study, *Accident Analysis & Prevention*, 49: 186-192.

RULE BENDING IN THE ROAD BASED COMMERCIAL GOODS TRANSPORT SECTOR - A SYSTEMS THEORY APPROACH

Christian Henrik Alexander Kuran[1], Ove Njå[2]
[1,2] University of Stavanger, Norway

Abstract: Intentional bending of safety related rules by actors in the road based commercial goods transport sector is a significant but understudied phenomenon. The sector in question is characterized by its complexity, the large number of actors involved, and by being hard to regulate. Cross border- and multimodal transport activities is a central contributor to the sectors complexity. The difficulty of introducing and enforcing workable international safety regulations and standards on international business is apparent; when we consider that individual actors working in different phases of the transport chain are often bending rules. We approach rule bending using systems engineering analyses of safety. The paper presents findings form the initial part of an ongoing double layer-category focus group design. Grey areas of rule bending in the transport chain was discussed in three focus groups consisting of transport workers, terminal workers and transport managers. The preliminary findings show that both self-reported and observed bending of rules is common in the phases of the transport chain explored in the study. Commonplace rule bending may lead to a breakdown in the feedback loop necessary to maintain safety as an emergent aspect of the transport system.

Keywords: rule bending, road based transport, safety engineering, focus groups.

1. Introduction

In this paper, we present the initial findings from three focus group interviews, and outline the potential for systems theory as a theoretical framework for analysis of rule bending in the road based commercial goods transport sector. (Leveson 2011) It is common knowledge that safety related rules are bent and even broken in many different sectors of society. Rasmussen and Svedung state that in the case of complex sociotechnical systems that indeed: "Rules and laws are never followed to the letter practically speaking". (Rasmussen & Svedung 2000:13) Rule bending is an understudied phenomenon in the road based commercial goods transport sector, and the regulatory bodies have a tendency to suppose that rule and regulations are usually followed. (Njå, Braut et al. 2012) The interviews discussed are the first three in an ongoing PhD-project, which also includes literature reviews, ethnographic fieldwork and survey methods. The project uses a joint framework of systems theory of complex sociotechnical systems, and ethnographic methodology. (Gobo 2008, Leveson 2011)
Rule bending as an academic term is commonly used in sociology of law (Canales 2011), and may be defined according to Sereka and Solin as following: "Rule bending involves a decision to go around the formally stated obligations by not fully following a rule, requirement, procedure or certification in totality" (2007). There are two problems with this definition. First, that it presupposes both the rule benders knowledge of, and intent to go around a rule or stated obligation in order for his actions to qualify as rule bending. Thus, the definition both excludes intentional and non-intentional lack of knowledge of said rule or obligation. During controls and audits in the road based commercial goods transport sector, ignorance of safety related rules and regulations does not excuse either rule bending or rule breaking. Second, the definition does not problematize that the bending of rules has a highly subjective component, as illustrated in figure 1. The same action described as rule bending by a transport company could be considered rule breaking by a government controller. The project of which this paper is a small component, aims to describe the grey areas of rule bending by charting variance in the performance, justification and rationalization of rule bending behavior in the transport sector.

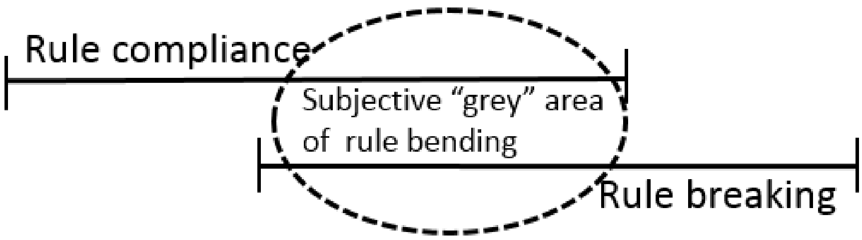


Fig. 1.
Subjective area of rule bending

2. Theory

The need for a systems theory perspective to be utilized in the analysis of safety and accidents in the road traffic sector is being voiced by several transport researchers. (Salmon, Read et al. 2012, Scott-Parker, Goode et al. 2015, Young and Salmon 2015) In systems theory sociotechnical systems are analyzed by analytically reducing the systems to a

[1] Corresponding author: christian.h.kuran@uis.no

hierarchical model, describing control through constraints, such as regulation and policy from one level of the hierarchy to the levels beneath it. (Salmon and Lenne:2015) In systems theory safety is described as an *emergent* property of the system. The reference channel and measuring channel is utilized in such a way as to allow a feedback loop from operational experience to be reflected in the goals, policies of the higher levels in the system and allowing for the control commands to be utilized properly. The reference and measuring channels are illustrated in figure 2.

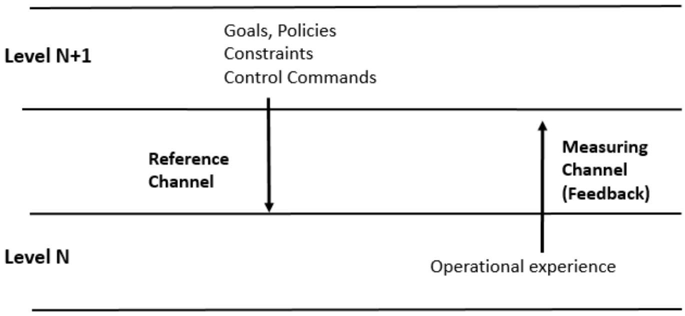


Fig. 2.
Hierarchic control structure in systems theory
Source: (Leveson 2011:83)

A hierarchical model of sociotechnical control in the road based transport sector is described in figure 3. The sampling of informants in the focus group study has been made in order to cover the company, operations and operating process levels in the model.

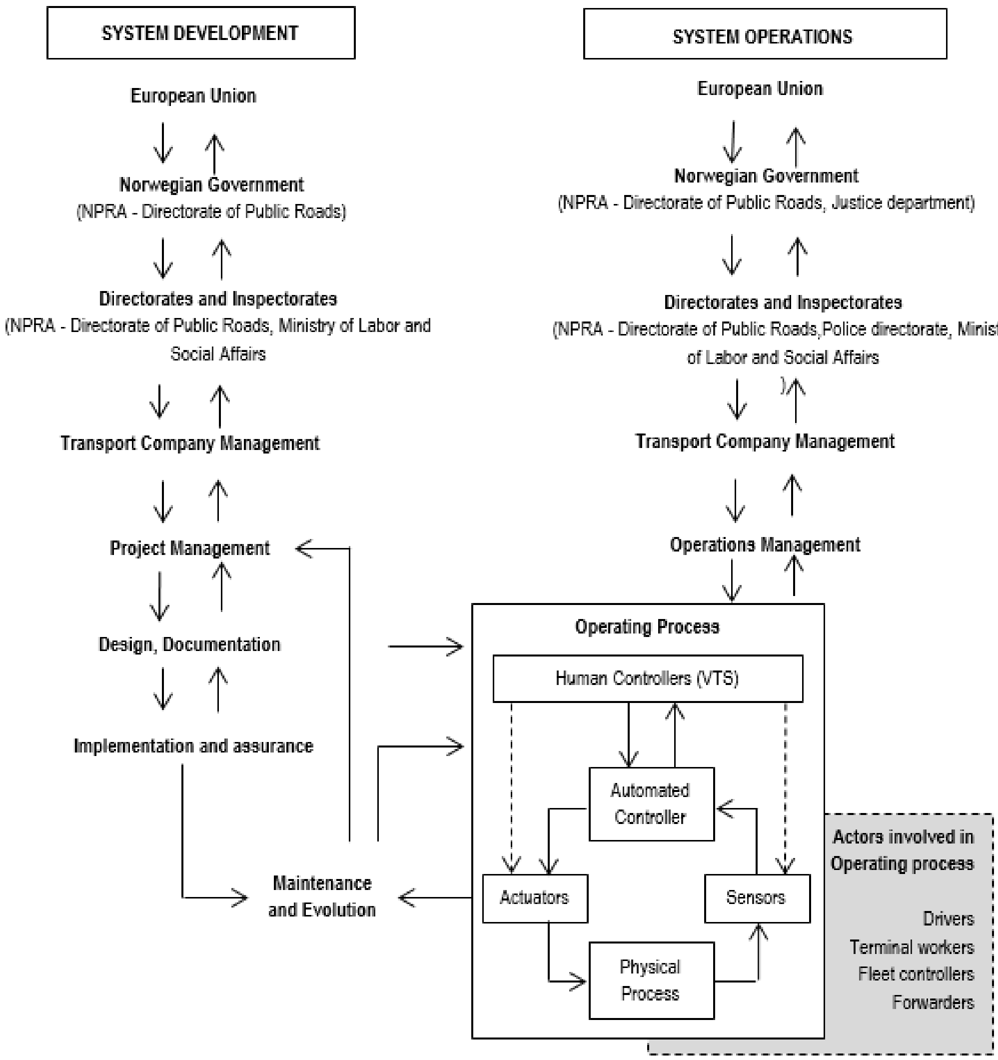


Fig. 3.
Model of sociotechnical control in the road based transport sector
Source: (Leveson 2011:82)

3. Method

In the sampling of informants for the three focus group interviews we made use of a “purposeful sampling strategy’(Creswell 2012), in which we reflected on whom to recruit. Our purpose of using focus groups in this study is to recruit a group of people each with a certain set of experiences and knowledge, to discuss rule bending. (Bernard 2006:323) We established a formal setting where all the informants where aware of the goal of the study, and where the moderator started each group by introducing the theme of the study. The moderator further guided the conversation with open-ended questions and ensured that all of the members contributed. The interviews where audio recorded, and the audio was transcribed shortly after the interviews in order ease the transcription process.
We recognized two major challenges during the data collection. First, that some participants dominated the conversation and compromised the available speaking time of other participants. Second, that some participants may for differing reasons have felt the need to censure their opinions or omit experiences. The reasons for non-compliance may stem from the fact that rule bending can be considered a sensitive topic. Our recognition of these two challenges guided out data collection. In the three focus group interviews, we attempted to dismantle hierarchy by reminding the participants that they have similar background, field of interest and social characteristic. (Krueger and Casey 2015) The moderator also fostered a certain methodological naiveté during interviews, allowing the participants to explain certain concepts or procedures in detail.
Our categorization and recruitment of informants for the interviews was guided by the categorization implicit in the hierarchical structure of systems theory. (Leveson 2011) All informants have so far been recruited from local companies and from local branches of national transport companies in Stavanger, in Western Norway and Fredrikstad, in eastern Norway. In the project, our planned data collection so far consists of 12 focus group interviews, four categories of participants in what is called a double layer focus group design. (Krueger and Casey 2015) An overview of the groups is shown in in table 1.

Table 1
Double layer category focus group design

Category	Vest Norway	East Norway
Transport workers	00	00
Terminal workers	00	0
Fleet controllers	0	0
Transport managers	0	0
Mixed group	0	

The inclusion of a mixed focus group may be considered a small methodological experiment within the bounds of the study. Since heterogeneous groups are discouraged by the methodological literature, due to self censure, we have included one such group to see if self-censure will occur. The informant’s respective reactions and discussions about rule bending in their line of work will in turn increase our understanding of the behavior and rationality of actors in the sector. Findings in the study might also be applicable for the analysis of rule bending in other modes of transport. Each focus group concluded after an hour and a half of discussion, and followed the same thematic conversational guide as outlined in table 2.

Table 2
Conversational guide

	Moderator Task or Question
1.	The moderator presents the theme of rule bending in the commercial goods transport sector.
1.	The moderator ensure that all group participants in turn present themselves, and their work tasks.
2.	The moderator ensure that all group participants in turn are invited by the moderator to say a few thoughts on the topic by answering the following question: - What kind of experiences do you have with safety related rules being stretched or bent in your place of work?
3.	The moderator opens free discussion of the topic
4.	The moderator guides the conversation back to the topic if the informants trail of for long.
5.	The moderator ensure that the discussion does not de-rail using one or several of the questions below. The same question may put more than one time to different participants. 1. What does a standard work process start? 2. Where in the transport chain is your work process? 3. Can you describe a task? 4. Who do you communicate with during the performance of a task? 5. What experiences have you with that rules are stretched in the business? 6. Can you / you give an example of a way to bend the rules? 7. I have focus group participants in other interviews who have other responsibilities and

	tasks such as dispatchers, drivers, terminal workers or fleet managers, do you have experience with that they are pushing rules? 8. How do they do it? 9. Does it affect you? 10. Why do you think safety related rules are bent during the transport chain? 11. How are experiencing control from the authorities? 12. Can you give an example of a control? 13. Concluding and summarizing question: Is it realistic to expect that some of your tasks always adhere strictly to the rules?

The subject of this paper, three groups, have so far been moderated:

3.1. Group 1

Group 1 was a homogenous group comprised of four terminal workers in a small company in West Norway. Each of the workers had several years of experience in the transport sector, and as terminal workers in the current and other companies. There was little or no self-censure and several examples of self-reported and observed rule bending was described by the participants.

3.2. Group 2

Group 2 was a homogenous group comprised of three transport workers with several years of experience as truck drivers in both local distribution and transnational transport. All where currently active in the transport sector and based in eastern Norway. There was no self-censure and several examples of self-reported and observed rule bending was described by the participants.

3.3. Group 3

Group 3 was a heterogeneous group comprised of a transport manager, a fleet manager and transport worker, and a terminal manager. The mixed group was characterized by some self-censure. Still many examples of self-reported rule bending was described by the participants.

4. Findings

In the course of the focus group interviews 22 concrete examples of rule bending behavior was self-reported or described by the informants. An overview of the behavior is shown in tables 3, 4 and 5, along with the Norwegian or EU law, regulation or directive it is associated with and divided by category.

Table 3
Rule bending actions self-reported or observed among transport workers described by informants in the focus group interviews

Rule Bending Task	EU/Norwegian Rule, Regulation Bent or Broken
Trucks loaded with inappropriate cargo, or inappropriate combination of cargo	FOR-2009-04-01-38 (Directive on professional transport), LOV-1974-12-20-68 (law on transport agreements)
Not loading or emptying own vehicle	LOV-1965-06-18-4 (law on road traffic)
Violating hours of service or rest hours regulation	FOR-2012-06-28-794 (AETR agreement)
Alerting other drivers about road side controls	FOR-2009-05-13-590 (Directive on road side controls)
Use of illegal or falsified documents	FOR-2009-04-01-384, LOV-1965-06-18-4 (Law on road traffic) FOR-2008-04-16-362 (directive on
Failure to have the proper documentation for cargo	FOR-2003-03-26-40 (Directive on commercial transport) , FOR-2009-04-01-384
Arbitrary truck maintenance	FOR-1994-10-04-918 (directive on vehicles)
Not securing container legs	LOV-2005-06-17-62 (law on working environment)
Not aiding in the unloading or loading of cargo	LOV-1965-06-18-4 (Law on road traffic)
Bypassing equipment used measure service and rest hours	FOR-2012-06-28-794 (AETR agreement),
Use of intoxicants such as alcohol	LOV-1965-06-18-4 (Law on road traffic)

Table 4
Rule bending actions self-reported or observed among terminal workers described by informants in the focus group interviews

Rule bending task	Rule, Regulation or Norm in Breach
Loading and fastening not appropriate for cargo or vehicle	FOR-2003-03-26-401 (directive on commercial transport along roads)
Loading and fastening of cargo not done by part responsible for cargo	FOR-2003-03-26-401 (directive on commercial transport along roads)
Handling loading, unloading of heavy equipment without the proper safety documentation	LOV-2005-06-17-62 (law on working environment)
Not documenting near-accidents	Directive (EU) 2015/413 – sharing information on road traffic offences

Table 5
Rule bending actions self-reported or observed among terminal workers described by informants in the focus group interviews

Rule bending task	Rule, Regulation or Norm in Breach
Drivers pressured by management to break speed limits or rest.	FOR-2005-06-10-543 (Directive on working hours for drivers and others in the road transport sector)
Collective freights badly managed	LOV-1974-12-20-68 (law on transport agreements)
Planning unrealistic or illegal routes	FOR-2005-06-10-543 (Directive on working hours for drivers and others in the road transport sector) FOR-2007-07-02-877(Directive on drive and rest – hours within the EES)
Not documenting near-accidents	Directive (EU) 2015/413 – sharing information on road traffic offences
Obscuring conditions at own workplace during control or audit	LOV-2005-06-17-62 (law on working environment) FOR-1996-12-06-1127 (directive on internal control)
Falsification of documents	FOR-2003-03-26-401 (directive on commercial transport along roads) FOR-2009-04-01-38 (Directive on professional transport)

All participants admitted that they “could get better at following rules”, but at the same time “that rules and regulations was often considered a hindrance for the flow of day to day business and problem solving”. An overview of which phase in the transport chain the described rule bending behavior was self-reported or observed is shown in figure 4.

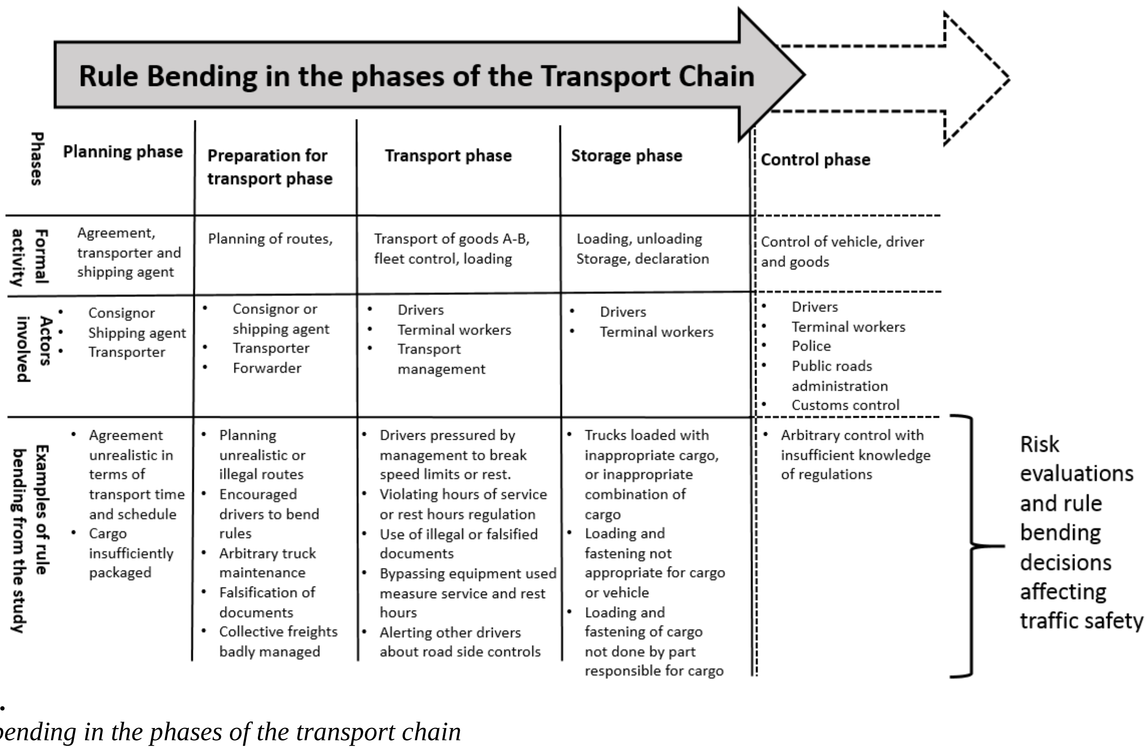


Fig. 4.
Rule bending in the phases of the transport chain

5. Discussion

In the focus group interviews several subjects where discussed in addition to the descriptions of different kinds of rule bending behavior. Examples include:

1. Does the lack of knowledge about safety procedures excuse rule-bending behavior?
2. When does the responsibility for the safety of a process enter or leave the individuals realm of responsibility?
3. Is it rule-bending behavior not to report or sanction observed rule bending behavior?
4. Can some rule bending behavior have possible positive effects?

While the informants recognized that rule bending behavior in several phases of the transport chain might in turn lead to unsafe condition and accidents, they urged that rule bending is an unavoidable necessity in their line of work, or “simply how business is done”. In discussing this further, the informants reported of perceived grey areas of responsibility between the necessity for rule compliance in order to preserve safety on one side, and on the other side the necessity to “cut corners” and “bend rules” in order keep their respective companies responsibilities to their customers, and continue to make a profit. Transport and terminal leaders communicate these twin factors of safety and profit in both subtle and not so subtle ways throughout the workday.

It is reasonable to consider that the grey areas rule bending might endemic in the commercial goods transport sector, in all phases of the transport chain. Grey areas where known to all informants in the study and highly prone to subjective interpretation by the individual. To maintain the flow of a work process and “live up to the expectations” of the companies customers, a transport manager will leave it to a transport worker to maneuver within a grey area where rules are bent and corners cut. The manager expects the worker to maintain the work process within reasonable bounds of safety but it is also known on both levels of the hierarchy that safety is the suffering part in the safety/profit dichotomy. The communication between the levels in the hierarchy about these grey areas is an informal one. This informal channel is shown in figure 5. as included in the systems theory model by the authors.

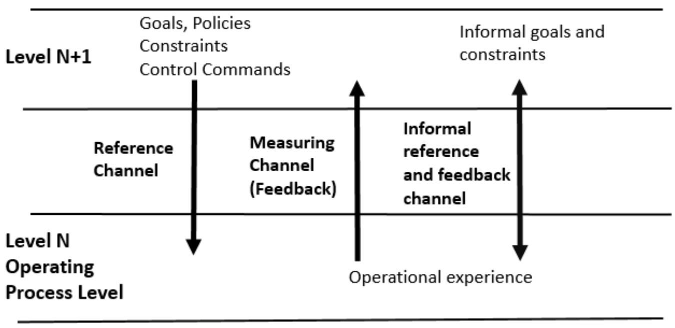


Fig. 5.
Hierarchic control structure with informal goals and channels
Source: (Leveson 2011)

It is possible to imagine grey areas of rule bending as an emergent property of the sociotechnical system. The consideration of alternative emergent properties in the road traffic system has also been the focus of research by Young and Salmon in their study on distracted driving as an emergent property of the road system. (Young and Salmon 2015) The maintenance of safety as an emergent quality of the transport system hinges on the continuous feedback loop of reference and measuring. As long as control and feedback is consciously utilized, the safety of the system will increase correspondingly. This perspective does not include that informal communication create grey areas of rule bending as continuous parts of the same system. Informal communication exists parallel to the feedback loop and may take precedence. This can lead to a breakdown of the measure and reference feedback loop, in turn reducing safety as an emergent property of the system.

6. Conclusion

The overall project will continue to observe and describe the creation and maintenance of grey areas of rule bending through informal communication, and their associated concrete methods of rule bending in the transport sector. More qualitative research is necessary in order to explore the informal practices, and the safety related consequences of rule bending. A focus group study is comprised of three or four group interviews in each category of participant, after which the researcher determines if saturation is achieved. (Krueger and Casey 2015:23) The term saturation describes a point in the research where the researcher does not attain any new information. This study has not reached yet reached that point, but we hope the overall project will.

Acknowledgements

The study is dependent on the continuous aid of both companies and individuals in the transport sector. For this, we are most grateful.

References

Bernard, H.R. 2006. *Research Methods in Anthropology*. Lanham, AltaMira Press.
Creswell, J.W. 2012. *Qualitative Inquiry and Research Design: Choosing among Five Approaches, 3d ed*. Washington DC Sage Michigan.
Gobo, G. 2008. *Doing Ethnography*, London SAGE Publications ltd.
Krueger, R.A.; Casey, M.A. 2015. *Focus groups: a practical guide for applied research*. Los Angeles, Calif, Sage.
Leveson, N. 2011. *Engineering a safer world systems thinking applied to safety*. Cambridge, Mass., Cambridge, Mass. MIT Press.
Njå, O.; Braut, G.S.; Vika, O. 2012. Bending rules in the commercial goods road transport sector, *Procedia - Social and Behavioral Sciences*, 48: 2336-2350.
Rasmussen, J.; Inge, S. 2000. *Proactive Risk Management in a Dynamic Society.* Karlstad, Sweden, Swedish Rescue Services Agency.
Rodrigo, C. 2011. Rule bending, sociological citizenship, and organizational contestation in microfinance, *Regulation and Governance*, 5: 90-117.
Salmon, P.M.; Lenne, M.G. 2014. Miles away or just around the corner? Systems thinking in road safety research and practice, *Editorial Accident Analysis & Prevention*, 74.
Salmon, P.M.; Read, G.J.; Lenne, M.G. 2012. Through a different lens: applying contemporary systems analysis methods in road safety, *Australasian Road Safety Research, Policing and Education Conference*. Wellington New Zealand, 48.
Scott-Parker, B.; Goode, N.; Salmon, P. 2015. The driver, the road, the rules … and the rest? A systems-based approach to young driver road safety, *Accident Analysis & Prevention*, 74: 297-305.
Sekerka, L.E.; Zolin, R. 2007. Rule-Bending - can prudential judgment affect rule compliance and values in the workplace?, *Public Integrity*, 9(3): 225-243.
Young, K.L.; Salmon, P.M. 2015. Sharing the responsibility for driver distraction across road transport systems: A systems approach to the management of distracted driving, *Accident Analysis & Prevention*, 74: 350-359.

STUDY ON BEHAVIORAL ANALYSIS OF DRIVERS: A SURVEY WITH QUESTIONNAIRES

Francesco Saverio Capaldo[1], Francesco Abbondati[2], Mario De Luca[3]
[1,2,3] Department of Civil, Architectural and Environmental Engineering (DICEA), University of Naples Federico II, Italy

Abstract: The road transport system is based on driving characteristics: a large amount of accidents is related to more or less serious violations of rules of the Highway Code. It is obvious that different drivers have different behaviors in the same situations, less obvious is to know what percentage of a given population has some similar behaviors (e. g. due to factors such as driving experience, age and/or sex) and how this knowledge can help in the road studies. To learn the driver's behavior, it can be useful to measure road speed (V_{85} or operating speed) in some default road situations (geometrical or environmental). Often the recorded data, when numerically significant, tend to a normal distribution. In some cases it is possible to define different data distributions where to was appreciated the contribution of two very different driver's behaviors. In order to better characterize the different driver's behavior a survey with questionnaires is started. The survey modules are composed with multiple sections. The starting section containing personal data is investigated with Dula Dangerous Driving Index (DDDI), Driver Behaviour Questionnaire (DBQ), Traffic Locus of Control Questionnaire (T-LOC), Marlowe Crowne Social Desirability Scale (MCSD), Car Selection (CS), Car Characteristics Selection (CCS). The questionnaire is filled by 300 persons, and the answers are checked and analyzed. For example with the DDDI, different driving styles are identified, with the DBQ some types of recurring errors. At the end it is possible to analyze the responses also in terms of age and sex and these have highlighted attitudes such as the driving anger, the risk perception, the potentially risky behavior, the anxiety, the perception of control, the respect for the rules. The results obtained indicate that the survey must be continued to improve the driver’s characterization.

Keywords: behavioral survey, driver’s behavior, behavioral questionnaires, driver’s characterization.

1. Introduction

Road transport is still dangerous: in Europe every year more than 1.2 million road accidents are recorded in which about 50,000 people die and 2 million are injured. Road accidents in Italy are the leading cause of death for people between 15 and 24 years. There are many causes of accidents due to factors related to vehicle, to safety devices, to road or to environment; often a combination of these variables is present, but the human factor still remains responsible for more than 80/90% of accidents. Many accidents are due to violations of road safety rules. The most typical violations are excessive speed, dangerous overtakings, unwary crossing, non-respect of safety distance, driving vehicles under bad mechanical conditions that are a threat to safety.

The driver is the best safety road device: this statement is true only if the driver is disciplined and well-informed on the road and flow conditions. Young people is a category of vulnerable drivers, because of their short time of driving experience. Young people is less skilled to estimate and perceive risks and often they challenge their own limits, overvaluing their own capabilities. The road accident is a probabilistic event where the lower attention of the driver increases the chances of putting in danger their safety and that of other persons.

The knowledge of the behavioral characteristics of drivers is very important in order to study road safety. Structural approaches to prevent road accidents (improving quality of roads and their design, introduction of active and passive safety systems in the construction of motor vehicles and other technologies) are beginning to produce positive results, but the unpredictable and wrong driver behavior still remains a strong obstacle to road safety.

The behavioral study can be led through different methodologies: road measures of the velocity vector (intensity, direction and variation) or its statistical determinations (operating speed, V_{85} etc) through different detection systems (Dell'Acqua and Russo, 2010 ; Dell'Acqua, 2011b; Discetti et al., 2011; Dell'Acqua et al., 2013c; Dell'Acqua, 2015; Capaldo, 2004b) or in different geometric conditions of road (Capaldo, 2012b; Capaldo and Biggiero, 2014).

A different approach uses answers directly from drivers on behavior and attitudes in certain situations and tries to correlate the given answers to some factors that can be measured in a different way. In this work the driver behavior is investigated with interviews of 300 persons with a set of different questionnaires, preceded by some personal information: Dula Dangerous Driving Index (DDDI), Driver Behaviour Questionnaire (DBQ), Traffic Locus of Control Questionnaire (T-LOC), Marlowe Crowne Social Desirability Scale (MCSDS), Car Selection (CS), Car Characteristics Selection (CCS).

The analyzed answers clarify certain behavioral aspects of the test subjects and also some correlations between the behavioral characteristics of some classes of age and the choice of the car and its main features.

2. Methodology and the different questionnaires

The work, shown here in a significant but not in a definitive step, starts from an initial data collection, limited to main behavioral questionnaires available in the literature. From personal data, regarding age, driving experience, suffered/caused accidents, the questionnaires collect information with: DDDI, DBQ, T-LOC, MCSDS (see Table 1). After analyzing the answers of 150 participants, two new sections are added to questionnaires: Car Selection (CS) regarding questions on choosing the car based on the price and Car Characteristics Selection (CCS) regarding questions

[1] Corresponding author: fcapaldo@unina.it

on the desirable characteristics of the chosen vehicle. For each participant were collected personal data as well as more than 100 responses for the different sections of questionnaires. Summary characteristics of each of the tests are shown in Table 1.

Table 1
Different questionnaires, autors and references, items for questionnaire, results and acronyms

Questionnaire	Autor/Ref.	Items	Results
Dula Dangerous Driving Index (DDDI)	Willemsen, J., Dula, C. S., Declercq, F., Verhaeghe, P. (2008)	27 items	Risky Driving Subscale (RDS) Aggressive Driving Subscale (ADS) Neg. Cognitive/Emotional Subscale (NC/ES) DDDI Dangerous Driving Total Score
Driver Behaviour Questionnaire (DBQ,)	Lajunen, T., Parker, D., Summala, H. (2004)	34 items (adapted)	Aggressive Violations Subscale (AVS) Ordinary Violations Subscale (OVS) Errors Subscale (ES) Lapses Subscale (LS) DBQ Total
Traffic locus of Control Questionnaire (T- LOC)	Ozkan, T., Lajunen, T. (2005)	18 items	Others Internal Vehicle/Environment Fate T-LOC Total
Marlowe Crowne Social Desirability Scale (MCSDS)	Crowne, D. P., Marlowe. D. (1960)	9 items (reduced)	Percentage of max value (9)
Car Selection (CS)	Capaldo, F. S.	9 items	Far desired passenger car
Car Characteristics Selection (CCS)	Capaldo, F. S.	7 items	Far desired car features

2.1. Dula Dangerous Driving Index

The wrong driving behavior is the result of emotional factors. For a long time scientific literature did not have a definition of the aggressive driving that could allow researchers to work on a common basis. To fill this gap, Dula and Geller (2003) propose an aggressive driving model based on three different attitudes while driving: ability to accept risk, intentional acts of aggression towards others, negative perceptions/emotions.
These factors are measured with the DDDI (Dula, Ballard, 2003), which shows adequate psychometric properties. Different test studies found that risky driving shows strong correlations with the number of received violations and the number of road accidents. In most cases, men report higher scores of aggression than women.
The questionnaire consists of 27 statements that express a positive or negative attitude to a specific object. The sum of these judgments tends to outline the driver attitude. For each statement, respondents are asked to indicate the level of agreement or disagreement in a defined scale, specifically a 5 step scale in this work.

2.2. Driver Behavior Questionnaire

Even in Italy, as mentioned before, at least 80/90% of accidents is due to inappropriate driver behavior, therefore it is legitimate to say that most of accidents are due to incorrect driving rather than technical reasons. To analyze driver behavior deeper it is necessary to evaluate his reactions in different circumstances.
Reason (1991) defines an error in all the cases where a planned sequence of physical or mental activities fails its purpose and when this failure cannot be attributed to the intervention of some random agent. More in detail a driver's risk behavior may be due to errors or violations. Unlike errors, violations are defined intentional, although both can be potentially cause accidents.
In later studies Lawton (1997) extends the scale of the violations to incorporate new elements. Factorial analysis shows that violations can be divided into two types, depending on the reason why drivers violate: aggressive violations, in which there is a violent interpersonal component, and regular violations, deliberate but in which there is not necessarily an aggressive purpose.
Another factor that distinguishes the driver's behavior is not intentional actions, but lapses, which is related to inattention or memory gaps that may occur while driving.
DBQ is used to evaluate these elements and it is used in studies conducted in the UK and in other international contexts. Data are collected from: Australia (Blockey and Hartley, 1995), China (Xie et al., 2003), Greece (Kontogiannis et al., 2002), Finland and the Netherlands (Lajunen et al., 1999; Mesken et al., 2002), New Zealand (Sullman et al., 2000), Sweden (Åberg and Rimmö, 1998), and Turkey (Sümer et al., 2002).
The original structure of the questionnaire (Reason, 1990; Reason et al., 1990) is based on four factors: aggressive violations, ordinary violations, errors and lapses. This work investigates 34 situations with 6 evaluation steps.

2.3. Traffic Locus of Control Questionnaire

The T-LOC can be defined as the degree to which the person generally perceives external events and classifies them within their ability to control, within the control of other subjects, to external factors (e. g. due to environment) or to fate.

The concept of locus of the internal / external control is endorsed for the first time in 1954 by Julian Rotter (Rotter, 1954) and there are two kinds. *Inside* is the kind owned by drivers who believe in their ability to control events. These subjects attribute their successes or failures to factors directly related to the use of their skills, willingness and ability. *Outside* is the kind held by those who believe that the incidents are not the direct result of personal capacity, but of unforeseeable factor such as other subjects, external factors or the case, fate. This work investigates 18 situations with 5 steps.

2.4. Marlowe Crowne Social Desirable Scale

Some participants, compiling questionnaires that assess their personality, temperament or behavior, tend to emphasize their best points and often deny or minimize their deficiencies and failures, trying to show that they are close to rules and standards of the civil society. Crowne and Marlowe (1960) develop a scale to identify the degree to which persons have this propensity. The original formulation include 33 items. In this survey the statements are reduced to 9 with binary response (true or false): this number is considered more than enough to provide a general indication on the behavior of the interviewed.

2.5. Choice of the ideal cars and their most desired features

In the survey, a list of cars, currently in production, divided by categories (City car, Small, Compact, Medium, Superior, Sport, SUV, Mini Van, Multi-space) is submitted to participants asking them to choose a model regarding the price or maintenance cost (CS, cfr. Table 1 for acronyms). A further section (CCS) showing the characteristics of the cars such as the power type (Petrol, Diesel, LPG/Methane, Hybrid, Electric) and other features (Reliability, Comfort, Consumption , Entertainment, Aesthetics, Manageability, Performance, Safety, Technology), asks if those features are essential or unnecessary for their ideal car. These last two sections try to investigate possible correlations between behavioral characteristics of participants and choice of car.

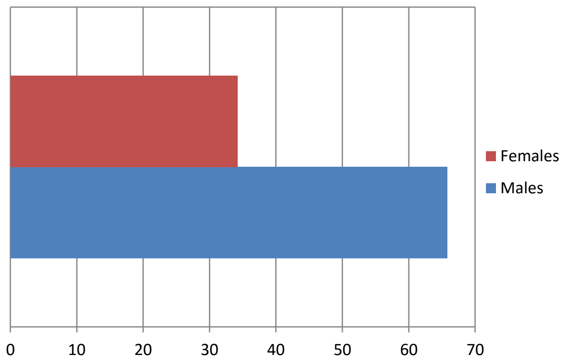


Fig. 1.
Survey data: Percentage of male and female subjects)

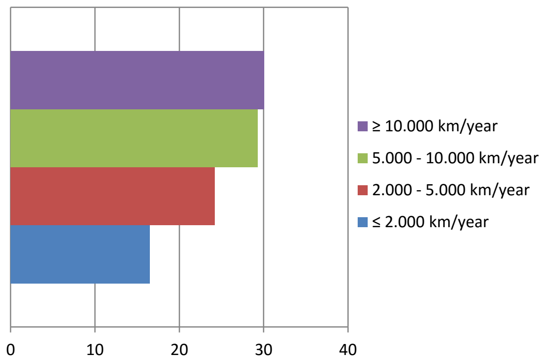


Fig. 2.
Survey data: Percentage of km/year of driving

3. Participants

The questionnaires are submitted to the students of the course of Construction Road, Railways and Airports of the University of Naples Federico II. So the sample is unbalanced because it is formed by young drivers with little experience. To balance the sample a set of questionnaires was dispensed to subjects with a different age.

A total of 300 drivers participated to the present study. The age range is between 19 and 74 years, with a mean age of 36 years and a prevalence of age between 19 and 35 years. 67% of drivers are men and 34% women. On average, the drivers have their license since 16 years and have driven approximately 10.000 km in the previous year (Table 2 and Fig. 2).

Fig. 3 shows the age distributions of the interviewed subjects compared with the adult Italian population and Fig. 4 the distributions of three different age classes adopted as regards to Italian population in 2015.

4. Data analysis and results

The DDDI, like the other indicators, is analyzed by sex and by age class of participants. The maximum values for each section are: 55 RDS (cfr. Table 1 for acronyms), 45 for NC/ES and 35 for ADS with a total value of 135 on 27 items. The graphs of Fig. 5 and 6 show the percentage difference of average values of the distributions for each section with respect to the central value of interval (e. g. 27.5 for the RDS).

Table 2
Survey data: some statistical parameters of participants (Age, Years of driving license, Km/year, Total accidents number)

Stat. Par.	Age	Lic. Years	Km/year	Tot. Accident N.
Min. Value	19,00	1,00	-	0,00
Max. Value	74,00	65,00	-	11,00
Average	33,86	15,95	10.476	0,82
Std. Dev.	14,23	13,22	6.812	1,32
85° perc.	54,00	34,20	-	2,00

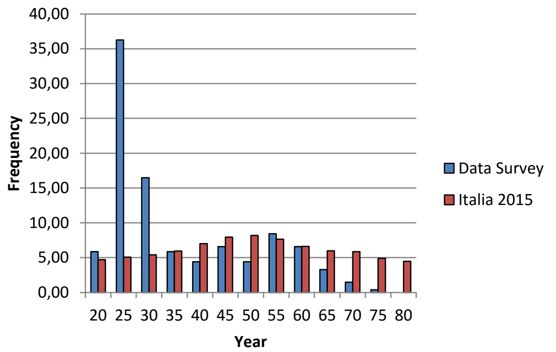


Fig. 3.
Difference between survey distribution classes and that of the Italian population by 2015

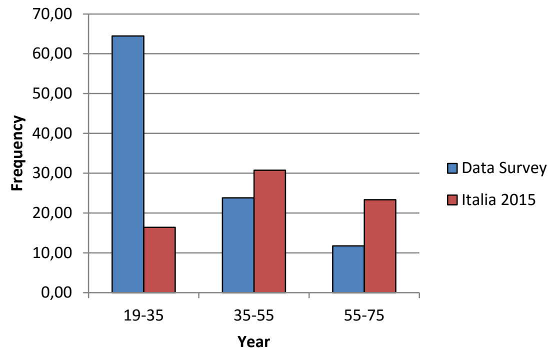


Fig. 4.
Difference between three distribution classes used with that of the same classes of the Italian population by 2015

Fig. 5 shows the experimental values as percentage differences relative to the central value of the interval of values for each subsection. The sample analyzed by gender indicates a total DDDI of about 8%, with women who have a greater difference than men (-10.1 and -7.3). The single factors analyzed show a trend similar for RDS and ADS and obviously opposite for NC/ES. The analysis by age group (see. Fig. 6) indicates that mainly participants over 55 (-15.0) contribute to the value obtained by DDDI, followed by those of other two classes (-13.4 and -5.3). Similar developments have RDS and ADS. For NC/ES those over 55 continue to maintain a basically positive attitude (-4.9) as well as to a lesser extent the 36-35 year class drivers (-1.0).

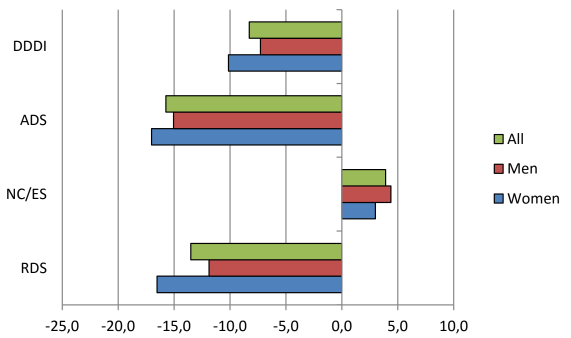


Fig. 5.
DDDI and subsection by participant sex

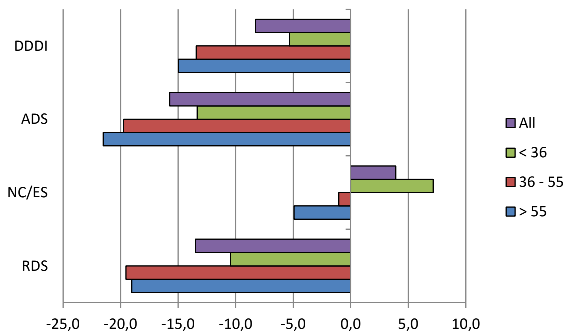


Fig. 6.
DDDI and subsection by participant age class

At end it can be said that almost all the participants have described themselves as very careful drivers. Male drivers are lesser cautious than females and younger drivers clearly lesser prudent than those over 55.
For the DBQ the same analysis and result presentation are done. Fig. 7 shows the values by gender and Fig. 8 by age group. The sample by gender shows, in Fig. 7, a total DBQ around -15.9%, with women who have a higher difference than men (-16.9 and -15.3). The single factors show a similar trend for Agg. Viol. (-15.8 and -15.6). Women are

significantly more correct than men for Ord. Viol. (-16.6 and -9.9) and tend to commit lesser errors (-22.2 and -21.3). However, they have declared themselves more vulnerable to lapses (-13.2 and -18.2). The analysis by age group (see. Fig. 8) shows that the best behavior (declared) is over 55 (-22.2) followed by the other two classes (-19.6 and -13.5). A similar trend is seen for all subsections of test.

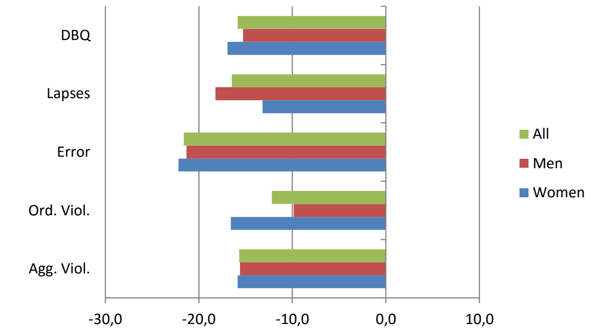


Fig. 7.
DBQ and subsection by participant sex

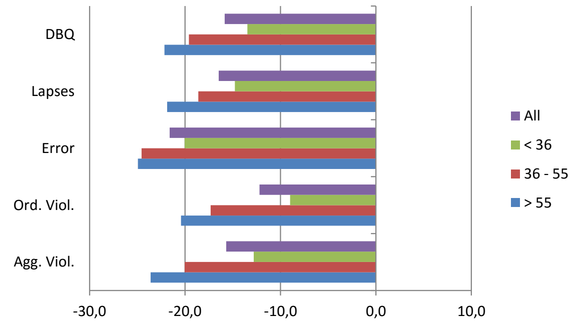


Fig. 8.
DBQ and subsection by participant age class

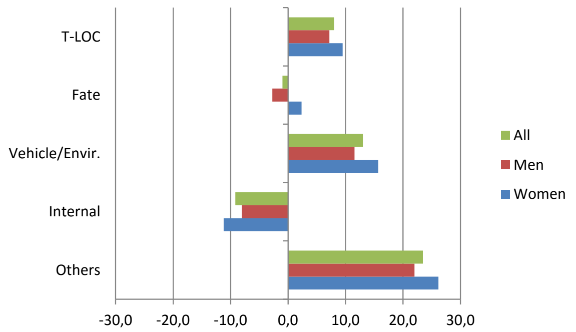


Fig. 9.
T-LOC and subsection by participant sex

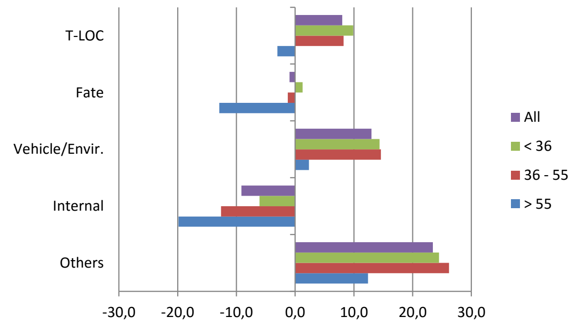


Fig. 10.
T-LOC and subsection by participant age class

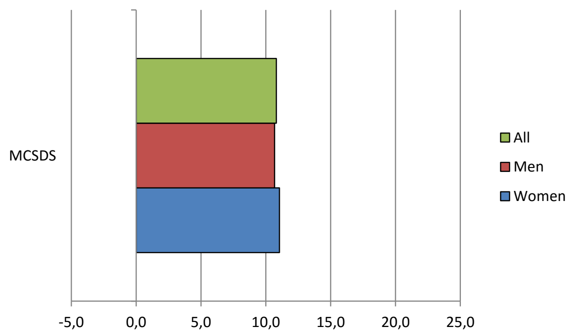


Fig. 11.
MCSDS and subsection by participant sex

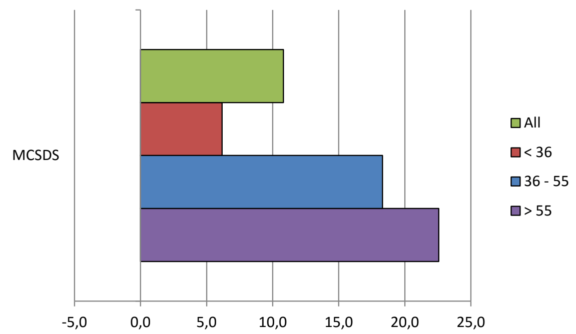


Fig. 12.
MCSDS and subsection by participant age class

Participants have declared a good driving behavior. Even in this case, the females seem better than the males, and younger drivers seem to have a worst behavior than those over 55.
The T-LOC (Fig. 9 and Fig. 10) closes the series of self-assessment questionnaires for drivers: it investigates what factors seem responsible for accidents not directly under their control (Others, Vehicle/Environment, Fate) and which under the driver's control (Internal). The factors independent from the driver's control are predominant. The gender analysis shows that women absolve themselves, imputing the possibility of an accident to factors out of their control. Men describe themselves slightly better and it seems that they do not believe in Fate in the case of accidents.
Considering the age groups, even drivers over 55 seem to be more inclined to admit their responsibility in a road accident, and they definitely exclude the possibility of an intervention of Fate.
At the end, drivers tend to blame all the possible faults of road incident to everyone except themselves. They believe that they might be involved in an accident for events that are not under their direct control and they are very sure of their driving skills.
But how much participants in their answers were sincere? It can make a judgment? Based on observations made by

other authors (Wahlberg et al., 2010; Lajunen and Summala, 2003; Fischer, 1993), the behavioral survey is completed with a smaller version of MCSDS. The results are shown in the graphs of Fig. 11 and Fig. 12.
It seems obvious that all the persons interviewed try to appear better and behaviors are quite similar when analyzed by gender. It has to be underlined that the difference from a neutral behavior (0% difference) is only about 10%. Younger persons seem more sincere than those of over 55 (Fig. 12). Overall, the result seems more than acceptable.
Table 3 shows the best correlation between the personal data of all respondents and total values of the questionnaires. The kilometers traveled / year and the number of accidents (fortunately very few for each subject; there is only one case with a total of 11 of which 8 under its own responsibility!) have a very little influence. Contrarily the results of the questionnaires appear very influenced by the subject age, by the years of the license acquisition and by the ratio between this information and age.

Table 3
Survey data: correlations between some parameters and result values of questionnaires

	Age	Lic. Years	Lic. Years/Age	DDDI	DBQ	T-LOC
Age	1					
Lic. Years	0,959314	1				
Lic. Years/Age	0,876014	0,951299	1			
DDDI	-0,412652	-0,404724	-0,39613	1		
DBQ	-0,444285	-0,427717	-0,41371	0,727783	1	
T-LOC	-0,286068	-0,284269	-0,24146	0,305104	0,289261	1
MCSDS	0,304299	0,273681	0,22802	-0,332601	-0,369179	-0,09551

A list of cars grouped into different categories (City car, Small, Compact, Medium, Superior, Sport, SUV, Mini Van, Multi space) is submitted to 120 persons interviewed. They have to choose only one according to their own preferences without considering the cost. After they have to identify which characteristics influence the choice of the car: Power / Fuel, Reliability, Consumption, Performance, Safety, Versatility / Adaptability, Aesthetics. The answers are limited to only three characteristics. For each category (CS) and each feature (CCS) a score is given according to the road safety. Fig. 13 and Fig. 14 show the percentages of the choices made by the participants for CS and CSS.

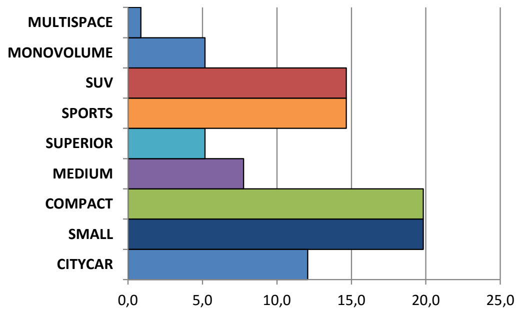


Fig. 13.
CS (Car Selection) percentage

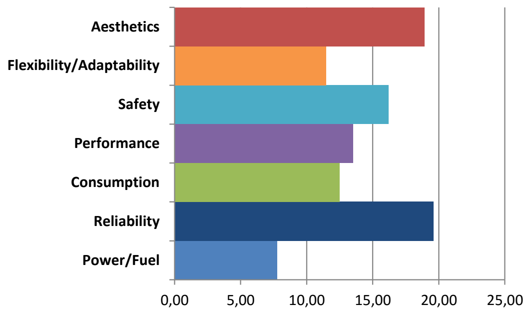


Fig. 14.
CCS (Car Characteristics Selection) percentage

Table 4
Survey data: correlations between ratio Years of driving license/Age, CS, CCS, CST and DDDI

	Lic. Years/Age	CS	CCS	CST	DDDI
Lic. Years/Age	1				
CS	-0,22639	1			
CCS	-0,27983	0,426969	1		
CST	-0,30378	0,746412	0,920469	1	
DDDI	-0,43782	0,394630	0,313871	0,401545	1

Table 4 indicates that the best correlation is between the sum of the scores assigned to CS and CCS (CST) and the DDDI index. Other correlations with different indices and the characteristics of the cars have given worst results.
Fig. 15 and 16 show DDDI as a function of CST. Fig. 15 shows the Total DDDI and Fig. 16 the DDDI referring only to male subjects. Both figures show that a correlation exists between the choice of the car, its characteristics, and the greater or lesser aggressive behavior of drivers. This relationship requires further investigations. This part of analysis concerns only 120 interviews compared with nearly the whole 300. The link between the choice of the characteristics of

the car and score obtained with DDDI is stronger for males than females. The analysis of age groups (<35, 36-55,> 55) shows that only for those over 55 the correlation between DDDI and CST has acceptable values although low. The other two classes have lower values of the slope of fit line.

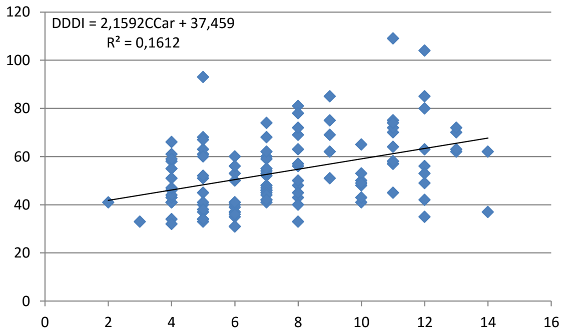


Fig. 15.
DDDI Total versus CST

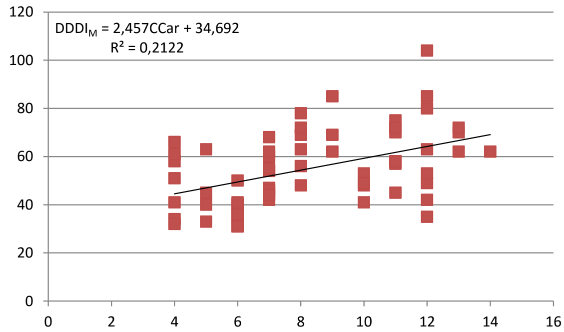


Fig. 16.
DDDI for men versus CST

5. Limitations

The surveyed sample has a prevalence of young peoples and this will be corrected with subsequent interviews. Even the statistical analysis is limited to a few essential indicators. At the end of this work it is not possible to include other 150 questionnaires already filled.
The study is limited by the perceived biases associated with self-report methodology, and in particular the potential for obtaining socially desirable responses (Wåhlberg et al., 2010). Importantly though, Lajunen and Summala (2003) directly examine DBQ responses and find that the influence of social desirability on responses is not substantial and is lesser when completed in privacy. Participants in the current study complete the questionnaires in their own time and the confidentiality of their responses is assured. Therefore, the impact of social desirability on responses is minimal: the reduced MCSDS value is about 10% (value determined as the percentage difference between the average experimental MCSDS and its central value of definition interval).

6. Conclusions

The goal of this work is to investigate through known questionnaires on driving attitudes a large, representative sample of Italian drivers. During the data collection it was thought that might somehow try to correlate attitudinal results of drivers to external elements such as the car models or something on the car characteristics or his choice.
The survey (now and even if with some limitations) collects a large number of information on drivers for different age groups, involves 300 subjects who provided, through the answers, at least 45.000 elementary information that is still under partial processing.
Data are collected through known questionnaires (DDDI, DBQ etc) and a control of the reliability of the answers is provided (MCSDS). This work tries to correlate some of the DDDI results with information supplied by interviewees that concerned the choice of the car. Preliminary results show a clear correlation between aggressive drivers and high-powered cars and/or sport cars.
In transportation simulations field conditions, road geometry and driver behavior in traffic flows must be replicated and driving behavior is one of the crucial points in modeling traffic flows as highway traffic or road maneuvers.
An increase of the survey data and the use of different statistical analysis on large amounts of information (e. g. covariance analysis, factorial analysis, data mining etc) will lead to more reliable results and will enable to recognize prevailing attitudes of drivers by recording the car models in traffic flows.

Acknowledgements

Special thanks to all those who contribute to this work and the patience they have by compiling long form; among them the students of the courses of Construction Road, Railways and Airports at University of Naples Federico II, their parents and all the others involved.

References

Abbondati, F. et al. 2016. Linear scheduling analysis toolkit for road and airports construction projects, *ARPN Journal of Engineering and Applied Sciences*, 11(11): 6863-6874.
Alberico, I. et al. 2012. Mapping the vulnerability for evacuation of the Campi Flegrei territorial system in case of a volcanic unrest, *Natural Hazards*, 64(2): 1823-1854.
Blockey, P.N.; Hartley, L.R. 1995. Aberrant driving behaviour: errors and violations, *Ergonomics*, 38(9): 1759-1771.

Capaldo, F.S. 2004a. A behavioral model of flows on roundabouts. In *Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering*, 301-306.
Capaldo, F.S. 2004b. A behavioural driver model for two lane roads. In *Proceedings of 4th International Conference on Traffic and Transportation Studies*, 803-810.
Capaldo, F.S. 2012a. Road Sight Design and Driver Eye Height: Experimental Measures. In *Proceedings of the 5th SIIV International Congress on Sustainability of Road Infrastructure, Procedia Social and Behavioral Sciences*, 732-741.
Capaldo, F.S. 2012b. Passing Maneuver: Survey, Some Models and Simulations. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 589-597.
Capaldo, F.S. 2012c. Driver Eye Height: Experimental Determination and Implications on Sight Distances. In *Proceeding of the 8th International Conference on Traffic and Transportation Studies (ICTTS)*, 375-383.
Capaldo, F.S.; Grossi, R. 1996. Automatic system for the definition of the setting rules for speed diagrams. In *Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering*, 193-197.
Capaldo, F.S.; Nasti, G. 2012. Analysis of Road Safety: Three Levels of Investigation. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 185-192.
Capaldo, F.S.; Biggiero, L. 2012. Some Surveys in order to Static Traffic Light Coordination. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 313-320.
Capaldo, F.S.; Biggiero, L. 2014. Experimental Survey and Modeling for the Driver Behavior in Vehicle Platoons. In *Proceedings of the 9th International Conference on Traffic and Transportation Studies (ICTTS)*, 279-288.
Capaldo, F.S. et al. 2000a. Accidents and geometric characteristics of road layout: Some quantitative evaluations. In *Proceedings of the 2nd International Conference on Traffic and Transportation Studies (ICTTS 2000)*, 80-87.
Capaldo, F.S. et al. 2000b. Airport capacity according to ICAO rules: Some quantitative evaluations. In *Proceedings 2nd International Conference on Traffic and Transportation Studies (ICTTS 2000)*, 803-810.
Capaldo, F.S. et al. 2012. Passing Maneuver: Models, Surveys and Simulation. In *Proceedings of the 8th International Conference on Traffic and Transportation Studies (ICTTS)*, 790-798.
Čavka, I. et al. 2014. Learning from errors–case study of an aircraft accident. In *Proceedings of the International Conference on Traffic and Transport Engineering*, 444-450.
Čokorilo, O. et al. 2014. Aircraft safety analysis using clustering algorithms, *Journal of Risk Research*, 17(10): 1325-1340.
Crowne, D.P.; Marlowe, D. 1960. A new scale of social desirability independent of psychopathology, *Journal of Consulting Psychology*, 24(4): 349-354.
Dell'Acqua, G. 2011a. Reducing Traffic Injuries Resulting from Excess Speed Low-Cost Gateway Treatments in Italy, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 94-99.
Dell'Acqua, G. 2011b. European speed environment model for highway design-consistency, *Modern Applied Science*, 6(9): 1-10.
Dell'Acqua, G. 2015. Modeling Driver Behavior by using the Speed Environment for Two-Lane Rural Roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2472: 83-90.
Dell'Acqua, G.; Lamberti, R. 2003. A Linear Scheduling Model to Plan Road Works. In *Proceedings of the XXII° World Road Congress*, CD-ROM.
Dell'Acqua, G.; Russo, F. 2010. Speed factors on low-volume roads for horizontal curves and tangents, *The Baltic Journal of Road and Bridge Engineering*, 5(2): 89-97.
Dell'Acqua, G.; Russo, F. 2011a. Road Performance Evaluation Using Geometric Consistency and Pavement Distress Data, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 194-202.
Dell'Acqua, G.; Russo, F. 2011b. Safety Performance Functions for Low-Volume Roads, *The Baltic Journal of Road and Bridge Engineering*, 6(4): 225-234.
Dell'Acqua, G. et al. 2005. Computer Based Linear Scheduling Application for Highway Construction Planning. In *Proceedings of the III° SIIV Congress*, Bari, Italy. CD-ROM.
Dell'Acqua, G. et al. 2011a. Indirect Skid Resistance Measurement for Porous Asphalt Pavement Management, *Transportation Research Record: Journal of the Transportation Research Board*, 2205: 147-154.
Dell'Acqua, G. et al. 2011b. Motorway speed management in southern Italy, *Procedia Social and Behavioral Sciences*, 20: 49-58
Dell'Acqua, G. et al. 2011c. Road safety knowledge-based decision support system, *Procedia Social and Behavioral Sciences*, 20: 973-983.
Dell'Acqua, G. et al. 2011d. Descriptors in Scenic Highway Analysis: a Test Study along Italian Road Corridors, *International Journal for Traffic and Transport Engineering*, 1(2): 73-88.
Dell'Acqua, G. et al. 2012a. Mix Design with Low Bearing Capacity Materials, *The Baltic Journal of Road and Bridge Engineering*, 7(3): 204-211.
Dell'Acqua, G. et al. 2012b. Procedure for Making Paving Decisions with Cluster and Multicriteria Analysis, *Transportation Research Record: Journal of the Transportation Research Board*, 2282: 57-66.
Dell'Acqua, G. et al. 2013a. Safety Data Analysis to Evaluate Highway Alignment Consistency, *Transportation Research Record: Journal of the Transportation Research Board*, 2349: 121-128.
Dell'Acqua, G. et al. 2013b. Risk-type density diagrams by crash type on two-lane rural roads, *Journal of Risk Research*, 16(10): 1297-1314.

Dell'Acqua, G. et al. 2013c. Validation procedure for predictive functions of driver behaviour on two-lane rural roads, *European Transport,* (53) paper 10.
Dell'Acqua, G. et al. 2016. The impact of vehicle movement on exploitation parameters of roads and runways: a short review of the special issue, *Transport*, 31(2): 127-132.
De Luca, M. 2015. A Comparison Between Prediction Power of Artificial Neural Networks and Multivariate Analysis in Road Safety Management, *Transport:* 1-7.
De Luca, M.; Dell'Acqua, G. 2012. Freeway safety management: Case studies in Italy, *Transport*, 27(3): 320-326.
De Luca, M.; Dell'Acqua, G. 2014a. Calibrating the passenger car equivalent on Italian two line highways: A case study, *Transport*, 29(4): 449-456.
De Luca, M.; Dell'Acqua, G. 2014b. Runway surface friction characteristics assessment for LameziaTerme airfield pavement management system, *Journal of Air Transport Management*, 34: 1-5.
De Luca, M. et al. 2011. Before-after freeway accident analysis using Cluster algorithms, *Procedia Social and Behavioral Sciences*, 20: 723-731.
De Luca, M. et al. 2015. Pavement Friction Decay: Preliminary Study in Lamezia Terme International Airport, Italy. In *Proceedings of the Transportation Research Board 94th Annual Meeting*, 15-0126.
De Luca, M. et al. 2016a. Field measurements on runway friction decay related to rubber deposits, *Transport*, 31(2): 177-182.
De Luca, M. e al. 2016b. Preliminary study on runway pavement friction decay using data mining, *Transportation Research Procedia*, 14: 3751-3670.
Discetti P. et al. 2011. Models of operating speeds for low-volume roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 219-225.
Dula, C.S.; Geller, E.S. 2003. Risky, aggressive, or emotional driving: Addressing the need for consistent communication in research, *Journal of Safety Research,* 34(2003): 559-566.
Dula, C.; Ballard, M.E. 2003. Development and evaluation of a measure of dangerous, aggressive, negative emotional, and risky driving, *Journal of Applied Social Psychology*, 33: 263-282.
Kontogiannis, T.; Kossiavelou, Z.; Marmaras, N. 2002. Self-reports of aberrant behaviour on the roads: errors and violations in a sample of Greek drivers, *Accid. Anal. Prev.*, 34: 381-399.
Fischer, D.J. 1993. Measuring Social Desirability: Short Forms of the Marlowe-Crowne Social Desirability Scale, *Educational and Psychological Measurement* SUMMER, 53(2): 417-424.
Lajunen, T.; Summala, H. 2003. Can we trust self-reports of driving? Effects of impression management on Driver Behaviour Questionnaire responses, *Transp. Res. Part F: Traffic Psychol. Behav*., 6(2): 97-107.
Lajunen, T.; Parker, D.; Summala, H. 2004. The Manchester Driver Behaviour Questionnaire: a cross-cultural study, *Accident Analysis and Prevention,* 36(2004): 231-238.
Lajunen, T.; Parker, D.; Summala, H. 1999. Does traffic congestion increase driver aggression?, *Transport. Res. Part F*, 2: 225-236.
Lamberti, R. et al. 2010. Visual impact assessment for infrastructure design, *Large Structures and Infrastructures for Environmentally Constrained and Urbanised Areas*: 668-669.
Lawton, R. et al. 1997. The role of affect inpredicting social behaviors: the case of road traffic violations, *J. Appl. Soc. Psychol.*, 27(14): 1258-1276.
Mauro, R. et al. 2013. Using a k-means clustering algorithm to examine patterns of vehicle crashes in before-after analysis, *Modern Applied Science*, 7(10): 11-19.
Reason, J.T. 1990. *Human Errors*. Cambridge University Press, Cambridge.
Reason, J.T. et al. 1990. Errors and violations on the road - a real distinction, *Ergonomics,* 33(10/11): 1315-1332.
Rotter, J. B. 1954. *Social learning and clinical psychology*. New York: Prentice-Hall.
Russo, F. et al. 2013. A statistical look at gender and age differences as related to the injury crash type on low-volume roads, *WIT Transactions on the Built Environment*, 134: 213-224.
Russo, F. et al. 2014a. Road Safety from the Perspective of Driver Gender and Age as Related to the Injury Crash Frequency and Road Scenario, *Traffic Injury Prevention*, 15(1): 25-33.
Russo, F. et al. 2014b. Consistent approach to predictive modeling and countermeasure determination by crash type for low-volume roads, *The Baltic Journal of Road and Bridge Engineering*, 9(2): 77-87.
Russo, F. et al. 2014c. Assessing Transferability of Highway Safety Manual Crash Prediction Models to Data from Italy, *Transportation Research Record: Journal of the Transportation Research Board*, 2433: 129-135.
Russo, F. et al. 2015. Driver Speed Behavior on Circular Curves of Undivided Two-Lane Rural Roads. Serbian and Italian Case Studies, *Transportation Research Record: Journal of the Transportation Research Board*, 2472: 117-128.
Russo, F. et al. 2016a. Safety performance functions for crash severity on undivided rural roads, *Accident Analysis and Prevention*, 93: 75-91.
Russo, F. et al. 2016b. Operating speed as a key factor in studying the driver behavior in a rural context, *Transport*, 31(2): 260-270.
Wåhlberg, A. 2010. Social desirability effects in driver behavior inventories, *J. Safety Res.*, 41(2): 99-106.
Wåhlberg, A.; Dorn, L.; Kline, T. 2011. The Manchester Driver Behaviour Questionnaire as a predictor of road traffic accidents, *Theoretical Issues in Ergonomics Science*, 12(1): 66-86.
Willemsen, J. et al. 2008. The Dula Dangerous Driving Index: An investigation of reliability and validity across cultures, *Accident Analysis and Prevention*, 40: 798-806.

Xie, C.; Parker, D. 2002. A social psychological approach to driving violations in two Chinese cities, *Transportation Research Part F*, 5: 293-308.

Zilioniene, D. et al. 2013. Evaluation of Climatic Factors Based on the Mechanistic-Empirical Pavement Design Guide, *The Baltic Journal of Road and Bridge Engineering*, 8(3): 158-165.

PEDESTRIAN LEVEL OF SERVICE ANALYSIS AND EFFECT OF ARCHITECTURE

Ilker Erkan[1]
[1] *Süleyman Demirel University Faculty of Architecture, Isparta, Turkey*

Abstract: This paper presents a literature review of pedestrian level of service (PedLOS) evaluation at various facilities such as sidewalks, intersections and crosswalk locations, and highlights the need for further Pedestrian LOS studies at crosswalks, under mixed traffic conditions, from the perspective of Turkey. The crosswalk is one of the most complex locations for pedestrians, bicycles, involving interaction with vehicular flow in different locations such as signalized or un-signalized crosswalks. The Complete Architectural Design Strategies (CADS) to be adopted for evaluation of a pedestrian facility changes with facility type. The Complete Architectural Design Strategies at crosswalks depends on numerous factors, including pedestrian safety, delay, available vehicular gaps and pedestrian as well as pedestrian behavior and vehicular driver behavior. In this case, it can be seen reflection of architecture. However, only limited studies have been carried on PedLOS using these factors. In this paper, the available literature is discussed, and the greater importance of sidewalks pedestrian level of service.

Keywords: pedestrian level of service, architectural utility, pedestrian dynamics, level of service, complete architectural design strategies.

1. Introduction and Literature Review

Assessment methods and level of service (LOS) standards vary according to the type of user (pedestrians, bicyclists, transit users, and vehicular drivers). In developing countries like Turkey, transport policies including roadway design and management, and investment programs, tend to favor of motorized traffic over non-motorized modes such as pedestrians and bicycles. Little attention has been given to reducing risk in non-motorized modes of transport. There is a need to provide mobility and ease of access for non-motorized modes, in order to help develop a sustainable transportation system. The design of such diverse user facilities is a complex task for Turkey's transportation engineers and designers. The Transportation Research Board (TRB, 2011) has defined the following definition for level of service:

- LOS A represents free flow,
- LOS B is in the range of stable flow, but the presence of other users in the traffic stream begins to be noticeable,
- LOS C is in the range of stable flow, but marks the beginning of the range of flow in which the operation of individual users becomes significantly affected by interactions with others in the traffic stream,
- LOS D represents high-density, but stable, flow and speed and freedom to maneuver are severely restricted, and the driver or pedestrian experiences a generally poor level of comfort and convenience,
- LOS E represents operating conditions at or near the capacity level and all speeds are reduced to a low, but relatively uniform value,
- LOS F is used to define forced or breakdown flow so this condition exists wherever the amount of traffic approaching a point exceeds the amount which can traverse it and queues begin to form, operations within the queue are characterized by stopping and starting".

In the case of transportation facilities, successive versions of the Highway Capacity Manual (HCM) have introduced new factors such as freedom to maneuver, traffic interruptions, comfort, and convenience (HCM, 2010).
Compared with motorized traffic, little attention has been paid to non-motorized road users such as pedestrians and bicycles under mixed traffic conditions. Rapid population growth and urbanization have produced a steep increase in the use of motor vehicles. The number of registered vehicles in Turkey increased from 10.236.357 in 2004 to 17.939.447 in 2013, an increase of 75.3% (TUIK, 2014). As the population continues to increase, transport behavior (pedestrian behavior and the number of vehicles) on the road are very important measures of life quality and mobility. Pedestrian walkways are used by a variety of users, including pedestrians with disabilities and wheelchair users. The design and evaluation of walkway facilities is therefore much more complex than roadway design (Landis et al., 2001).
On the other hand pedestrian level of service is first criteria that think about starting to design. Erkan et al. (2016) conducted an LOS study of the movement and circulation of elderly people in airports, and suggested that the mobility of elderly people is a key factor in Pedestrian level of service (PedLOS).
The first Pedestrian LOS study (Fruin, 1971) was based on capacity and pedestrian volume in sidewalk facilities. It calculated the CADS from pedestrian flow rates, pedestrian speed, and area modules (the inverse of pedestrian density). Several subsequent LOS studies have applied these measurable parameters to different walkway facilities (Polus et al. 1983, Tanaboriboon & Guyano, 1989). Researchers have identified problems with the freedom to choose pedestrian speeds at sidewalks, and have explored new factors like travel time and its relationship to density, defined as a queuing relationship (Rahman et al., 2013). Other studies have extended the pedestrian equivalent factor under heterogeneous traffic conditions to the evaluation of pedestrian facilities (Galiza & Ferreira, 2013).

[1] Corresponding author: ilkererkan@sdu.edu.tr

Pedestrian flow characteristics have also been used to evaluate facility of architectural design (like sidewalks, streets, urban furniture etc.), using parameters such as pedestrian speed, flow rate, and density as CADSs. Studies have been conducted at a range of at different locations, including central business district areas (Al- Masaeid et al. 1993) and passenger terminal locations (Yang, 2010). A range of linear models have been applied (Virkler & Elayadath, 1994) at different facilities (Lam & Cheung, 2000). Research has been conducted in mixed traffic conditions (Laxman et al. 2010), and using simulation based approaches (Teknomo, 2006). All these studies used quantitative approaches, and neglected qualitative factors such as comfort, safety, and street attractiveness.

2. Material and Method

We placed to Bluetooth device in the street that detecting pedestrian on the sidewalks. We count to pedestrians with these devices with Bluetooth sensors (Figure 1).

Fig. 1.
Bluetooth device that placed on the street

As methods to extract the count and flows of pedestrians from Bluetooth detection logs, while considering the data management scheme on a mobile ad hoc network (Nishide & Takada, 2012) in case study area (Figure 2) in Turkey.

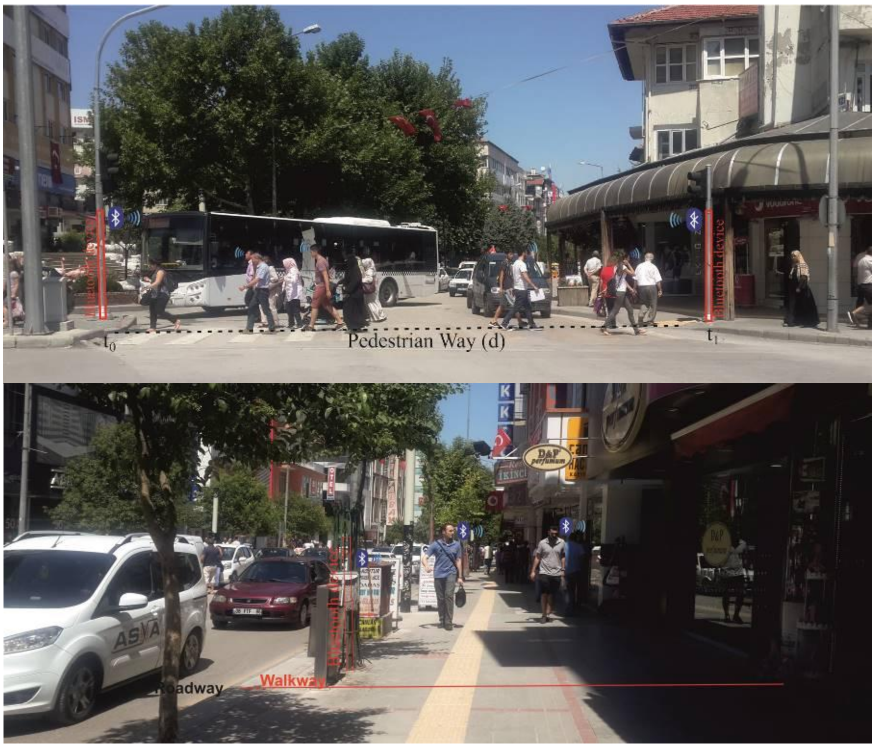


Fig. 2.
Case study area

All the observations were made by 1812 people. Results from such a small sample size cannot be generalized for large population. The aesthetic quality of the walking environment has a considerable influence on one's perception of safety and/or comfort but in our study participants were encouraged to disregard surroundings aesthetics when crossing the road.

In case study area, we determined number of pedestrian with Bluetooth device and analyzed pedestrian level of service according to Bureau of Public Roads (BPR) (1964) and Yuhaski and Smith (1989).

Bureau of Public Roads (BPR) (1964) model has been used by engineers for estimating travel times on road networks and determining to estimate pedestrian travel time on different walking facilities

$$t(k) = t_0 + A \cdot \left(\frac{k}{k_j} \right)^s \quad (1)$$

Where; t(k): travel time (sec) at flow level or density k, t_0: free-flow travel time (sec), k: pedestrian flow (pedestrian/m/sec) or density (pedestrian /m²), A, s: constants to be estimated in the model fitting procedure, k_j: the capacity of the pedestrian facility (pedestrian/m/sec or pedestrian /m²).
In addition that the pedestrian travel time is considered in the formulation of overall service rate and is given by Yuhaski and Smith (1989):

$$R = s\frac{1}{t(k)} = s\frac{1}{t_o - t_1} \quad (2)$$

Where; R: overall service rate of the area, s: the number of pedestrians (in the minimal length of the area), t1: time (sec.) of go in of a pedestrian in the area, t_0: time(sec.) of go out of a pedestrian from the area, t(k)=t0- t1: travel time(sec.) at density k.
We consider that level of service on this site with these formulations shown as Table 1.

Table 1
Level of Service at selected area

	Time	Level of Service
MORNING	08:00	A
	08:30	B
	09:00	C
	09:30	C
	10:00	D
	10:30	D
	11:00	D
	11:30	E
AFTERNOON	12:00	D
	12:30	F
	13:00	D
	13:30	D
	14:00	E
	14:30	D
	15:00	E
	15:30	D
	16:00	E
	16:30	D
	17:00	E
	17:30	D
EVENING	18:00	D
	18:30	D
	19:00	D
	19:30	D
	20:00	C
	20:30	C
	21:00	C
	21:30	C
	22:00	B
	22:30	B
	23:00	A
	23:30	A
	00:00	A

3.Discussion

Baltes and Chu (2002) analyzed the pedestrian mid-block crosswalk LOS with pedestrian-vehicle interaction as the difficulty factor, based on pre-selected participants, but not using realistic pedestrian crossings. A more recent study has shown the importance of pedestrian perceived safety and road crossing difficulty with realistic pedestrian crossings at mid-block crosswalks, under mixed traffic conditions (Kadali et al. 2013; 2015). The HCM (2010) rated mid-block LOS based on the difficulty factor, but did not relate the LOS to pedestrian safety. Researchers have distinguished between marked and unmarked mid-block crosswalk LOS (Zhao, Bian, Lu, & Rong, 2014). Existing PedLOS studies have explained the factors which need to be considered for the evaluation of pedestrian sidewalks and at intersections. Studies have mainly been carried out where sidewalks were well designed foot paths of paved blocks. However, in Turkey, pedestrians may share vehicular lanes, either because of the absence of sidewalks (space is available for pedestrians, but there are no proper facilities like paving blocks or curbs for separating pedestrian and vehicular movement), or because of obstructions on the sidewalk or discontinuity of sidewalks.

There is a need to consider a wider range of factors as MAU, such as safety, design and gap opportunities, for realistic evaluation of crosswalks. No studies have been carried out on pedestrian safety using LOS as the input, and such studies are especially important at unprotected crosswalk locations under mixed traffic conditions, in order to reduce pedestrian-vehicle conflicts.

Studies have pointed out that there is no single method which can exactly capture the field Pedestrian LOS with both qualitative and quantitative parameters (Sisiopiku et al. 2007). Researchers have developed a simulation model to analyze the conditions of environments with different roadway geometries (Talevska & Todorova, 2012), but these simulation models need to be calibrated with field data and architectural elements such as urban furniture, walkway design principles and also walkway design materials. Hence, the applicability of these models to mixed traffic conditions needs further investigation for architectural design and elements.

Existing simulation models are more appropriate for evaluation of facilities with different kinds of pedestrian attributes, and different environmental, traffic, and roadway characteristics. Studies have also shown the importance of segregation of non-motorized vehicles (bicycle) from pedestrian flow (Kang et al., 2013). In this matter, walkway design is very important factor for bicycles. But again, these studies were limited to the university campus, and it does not represent either typical field conditions or heterogeneous traffic conditions and also pedestrian behavior characterisrics. Several studies have explored different modeling techniques such as linear, polynomial regression, cumulative logit models and ordered probit models, in order to quantify the effect of selected variables on Pedestrian LOS at sidewalk locations.

Researchers have explored the use of nonlinear techniques to define the Pedestrian LOS categories for the pedestrian sidewalk LOS (Sahani & Bhuyan, 2014) and these non-linear techniques are even more powerful for the evaluation of unprotected mid-block crosswalk facilities, because of pedestrian behavioral characteristics. Research using a walkability index at crosswalk locations is lacking in developing countries. This should be remedied, as the walkability index is the most appropriate measure of the accessibility of pedestrian facilities.

These studies are required because free left turn is more common in developing countries, and roundabouts are more complicated for pedestrians attempting to cross, due to the absence of adequate gaps. Pedestrian LOS combining qualitative and quantitative factors and non-compliant behavior by pedestrians at crosswalk locations has not been addressed. Furthermore, most of these studies, whether carried out at sidewalk or crosswalk, do not explain the effect of pedestrian behavioral characteristics on Pedestrian LOS under mixed traffic conditions. We are therefore exploring the establishment of threshold values for the LOS grades, and defining a new MOB, for the evaluation of unprotected mid-block crosswalk locations under mixed traffic conditions.

Crosswalks are complex, either due to pedestrian behavior or to the intersection between pedestrian and vehicle driver behavior. Using delay as a single MAU, which is the conventional approach, is suitable for crosswalk Pedestrian LOS.When pedestrians are crossing at crosswalks, they display different behavioral characteristics (rolling behavior, speed as well as path change conditions etc.) and these behavioral characteristics play a major role in pedestrian safety (Kadali & Vedagiri, 2013). In developing countries, it has been observed that drivers are unlikely to yield to pedestrians waiting at curbs. The crossing difficulty and safety varies with the pedestrian behavior and traffic and roadway characteristics, as shown in Figure 3.

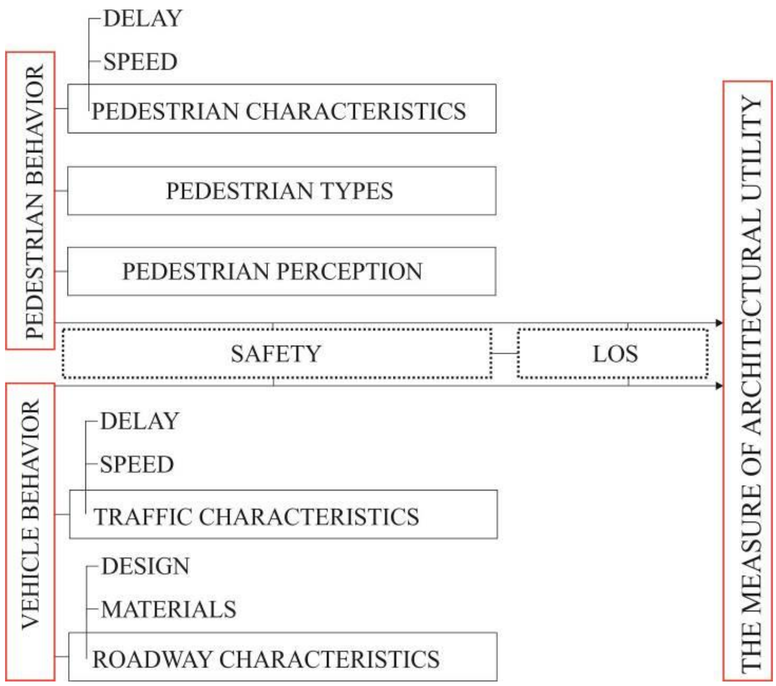


Fig. 3.
Evaluation of pedestrian LOS for MAU

In case study shows us, the difficulty, number of vehicles encountered by pedestrians while crossing and pedestrian safety should play major roles in MAU for Pedestrian LOS at unprotected mid-block crosswalk locations, alongside pedestrian delay (Kadali et al, 2015). The ease of pedestrian crossing depends upon the gap opportunities available to the pedestrian and pedestrian behavior changes with architectural elements.
The pedestrian behavioral changes while crossing depend on the interactions between pedestrians and vehicles. Furthermore, this change in pedestrian behavior may impact on pedestrian safety. The interaction between pedestrians and vehicles indirectly affects the service provided at crosswalks. So, the parameters which determine the pedestrian crosswalk LOS are mainly dependent on the behavior of the pedestrian.
However, the demographic characteristics of the pedestrian, particularly gender and age, also play a major role in both pedestrian behavioral characteristics and walking speed. So, demographic, behavioral, vehicular, traffic and roadway characteristics all need to be considered in modeling both pedestrian-vehicular interaction and safety model. These can then be incorporated into PedLOS studies at crosswalk locations. There is a need to address the pedestrian perception of delay and safety at particular crosswalks, and to develop combined models, in order to improve the quality of existing crosswalks.

3. Conclusion

Level of service is not sufficient factor for analyzing roads' safety and characteristics. Walkways, streets, roadways are most common things about analyzing road characteristics. So, "Complete Architectural Design Strategies" must a design principle by which all roadway users – motorists, bike riders, walkers, etc. – can safely move along and across a street. With road design policies like "Complete Architectural Design Strategies", bike/pedestrian-friendly roads are built routinely whenever roadwork occurs. On the other hand this paper is important for analyzing pedestrian stream with Bluetooth devices. In this sense this paper shows us that It is suggested that the analysis of motion in this way is cheap and simple.

Acknowledgements

Special thanks to participants and artisans' for contribution in this study.

References

Al-Masaeid, H.R.; Al-Suleiman, T.I.; Nelson, B.C. 1993. Pedestrian speed-flow relationship for central business district areas in developing countries, *Transportation Research Record: Journal of Transportation Research Board*, 1396: 69-74.
Baltes, M.R.; Chu, X. 2002. Pedestrian Level of Service for Midblock Street Crossings, *Transportation Research Record: Journal of the Transportation Research Board*, 1818: 125-133.
BPR 1964. Traffic Assignment Manual: Bureau of Public Roads, U.S. Department of Commerce, Washington, D.C., U.S.A.
Fruin, J.J. 1971. Designing for Pedestrian: A Level of Service Concept, *Highway Research Record*, 355: 1-15.
HCM. 2010. Highway Capacity Manual. Transportation Research Board, Washington, D.C., U.S.A.
Galiza, R.; Ferreira, L. 2013. A methodology for determining equivalent factors in heterogeneous pedestrian flows, *Computers, Environment and Urban Systems*, 39: 162-171.
Kadali, B.R.; Vedagiri, P. 2013. Marked versus unmarked pedestrian road crossing behavior at uncontrolled midblock crosswalk in mixed traffic condition. In *Proceedings of the* 92nd TRB Annual Meeting, Transportation Research Board.
Kadali, B.R.; Vedagiri, P.; Rathi, N. 2015. Models for pedestrian gap acceptance behaviour analysis at unprotected mid-block crosswalks under mixed traffic conditions, *Transportation Research Part F: Traffic Psychology and Behaviour*, 32: 114-126.
Kang, L.; Xiong, Y.; Mannering, F. L. 2013. Statistical analysis of pedestrian perceptions of sidewalk level of service in the presence of bicycles, *Transportation Research Part A*, 53: 10- 21.
Lam, W.H.K.; Cheung, C. 2000. Pedestrian speed flow relationships for walking facilities in Hong Kong, *Journal of Transportation Engineering*, 126(4): 343-349.
Landis, B.W.; Vattikuti,V.R.; Ottenberg, R.M.; McLeod, D.S.; Guttenplan, M. 2001. Modeling the roadside walking environment: A pedestrian level of service, *Transportation Research Record: Journal of the Transportation Research Board*, 1773: 82-88.
Laxman, K.K.; Rastogi, R.; Chandra, S. 2010. Pedestrian Flow Characteristics in Mixed Traffic Conditions, *Journal of Urban Planning and Development*, 136(1): 23-33.
Nishide, R.; Takada, H. 2012. Exploring Efficient Methods to Extract Pedestrian Flows on a Mobile Adhoc Network. In *Proceedings of The Sixth International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM 2012)*, 29-34.
Polus, A.; Schofer, J.L.; Ushpiz, A. 1983. Pedestrian Flow and Level of Service, *Journal of Transportation Engineering*, 109(1): 46-56.
Rahman, K.; Ghani, N.A.; Kamil, A.A.; Mustafa, A.; Chowdhury, A.K. 2013. Modelling Pedestrian Travel Time and the Design of Facilities: A Queuing Approach, *Plos One*, 8(5): 1-11.

Sahani, R.; Bhuyan, P.K. 2014. Pedestrian level of service criteria for urban off-street facilities in mid-sized cities. *Transport*, 1-12, in Press: http://dx.doi.org/10.3846/16484142.2016.1183227.

Sisiopiku, V.P.; Byrd, J.; Chittoor, A. 2007. Application of Level of Service Methods for the Evaluation of Operations at Pedestrian Facilities, *Transportation Research Record: Journal of the Transportation Research Board*, 2002: 117-124.

Talevska, J.B.; Todorova, M.M. 2012. Contribution to Sidewalk Pedestrian Level of Service Analysis, *Transport problems*, 7(3): 1-12.

Tanaboriboon, Y.; Guyano, J.A. 1989. Level-of-Service Standards Pedestrian Facilities in Bangkok: A Case Study, *ITE Journal*, 59(11): 39- 41.

Teknomo, K. 2006. Application of microscopic pedestrian simulation model, *Transportation Research Part F*, 9(1): 15-27.

TRB, Transportation Research Board, 2011. *Annual Report*, Washington, D.C., U.S.A.

Virkler, M.R.; Elayadath, S. 1994. Pedestrian speed-flow-density relationships, *Transportation Research Record: Journal of Transportation Research Board*, 1438: 51-58.

Yuhaski S.J.; Smith J.M.G. 1989. Modeling circulation systems in buildings using state dependent queueing models, *Queueing Systems*, 4(4): 319-338.

Zhao, L.; Bian, Y.; Lu, J.; Rong, J. 2014. Method to Determine Pedestrian Level of Service for the Overall Unsignalized Midblock Crossings of Road Segments, *Advances in Mechanical Engineering*, 1-9.

PEDESTRIAN BEHAVIOUR ON SIDEWALKS IN VARIOUS USERS CONDICTION

Francesco Pinna[1], Francesca Farci[2], Roberto Murrau[3]
[1,2,3] *Department of Civil Engineering, Environmental and Architecture DICAAR – University of Cagliari, Cagliari Italy*

Abstract: Living in a healthy urban environment is a growing and shared need that developed a greater sensitivity about the issue of pedestrian mobility. The walking freedom can define the quality of the urban area but this freedom is conditioned by various factors. The research objective is to study pedestrian behavior on sidewalks. The study area is the city of Cagliari (Sardinia-Italy) where nine sidewalks, characterized by the presence of activities and services for citizen, are analyzed. Data are collected during on site surveys by means of concealed camcorders. For each pedestrian many factors are observed, such as gender, age, direction, distractions, transport of objects, etc.., which could influence pedestrian behaviour. Data processing allow the identification of mathematical models describing the average pedestrians behavior, subdivided for user type (isolated, single, group).In general, the mean walking pedestrian speed decreases depending on user type (in linear manner if age class grows up for isolated pedestrians while with the square of age for others users types), of gender and of facing type. Results support the idea that, to define a smooth pedestrian speed as indicator of the "walkability" of a path, in addition to considering path and users characteristics is also necessary to define the type of user for which the infrastructure is designed.

Keywords: pedestrian behaviour, pedestrian speed, sidewalk, behavioural model.

1. Introduction

Walking has always been the fundamental element of urban life and represents an effective response to some of major problems of present days, like the urban vitality loss, the pollution and the deteriorating living conditions.
When pedestrian becomes the actor of the urban scenario, significant improvements are obtained in urban quality and individual people life.
Several scientific studies investigate factors affecting pedestrian behaviour.
Willis et al (Willis 2004) consider many factors such as age, gender, level of mobility, percentage of groups, time of day, etc., finding that walking speed decreases as age increases; in fact, youngest pedestrians have the highest speeds and adults are significantly faster than elderly pedestrians, who are the slowest category.
Finnis K. K. et al (Finnis 2007) measure the mean pedestrian speed to evaluate the influences on urban planning and pedestrian facilities design in rural and urban municipalities of New Zealand. Data show complex relationships between environment, personal characteristics of pedestrians and physical factors. These factors have been taken into account during the models construction for the study of pedestrian movements.
Rahman et al (Rahaman 2012) show that in Bangladesh free flow speed is strongly influenced by pedestrians age, gender and pedestrian facilities characteristics. In addition, the presence of luggage has greater influences on female pedestrian speed, compared to the male one.
Nazir M. I. et al (Nazir 2014) study pedestrian free flow speed on sidewalks of Rajshani city, in Bangladesh. Data are collected by camcorder. The study investigates the relationship among flow, speed, density and pedestrian space. Results show that the mean walking speed is influenced by age and gender, and that locations characteristics have effects on pedestrian flows.
For this reason, also this research have the objective to investigate pedestrian infrastructure characteristics, pedestrians characteristics and the behaviour that pedestrians take along paths. This paper is the development of a previous research carried out by the authors (Murrau 2014). These knowledges could be useful factors for pedestrian spaces good design.

2. Area of study

The observed area is Cagliari city (Sardinia - Italy). Selected streets are part of the urban context and are characterized by activities and services for citizens; nine sidewalk sections are chosen in these streets.
Data are collected by field video surveys, which allow to acquire the characteristics of 4872 pedestrians.
Sidewalks general data are reported in Table 1a/b.

Table 1a
General sidewalks characteristics

Sidewalks	Width [m]	Average Walking Speed [m/s]	Standard Deviation б	Pedestrian Volume	Men [%]	Women [%]	Groups [%]
Viale Trieste	2,15	1,20	0,28	715	58,0	42,0	24,6
Via Roma	3,45	1,37	0,27	970	57,5	42,5	33,2
Via B. Rossi	1,45	1,30	0,32	194	53,6	46,4	22,5
Via Sonnino	1,35	1,17	0,28	204	49,0	51,0	35,2
Via G. Deledda	2,05	1,35	0,31	508	47,0	53,0	46,5

[1] Corresponding author: fpinna@unica.it

Table 1b
General sidewalks characteristics

Sidewalks	Width [m]	Average Walking Speed [m/s]	Standard Deviation σ	Pedestrian Volume	Men [%]	Women [%]	Groups [%]
Via Paoli sez.1	2,85	1,21	0,32	795	39,8	60,1	28,1
Via Paoli sez.2	3,95	1,17	0,40	939	38,0	62,0	30,7
Via Leopardi	2,50	1,25	0,30	280	46,0	54,0	39,8
Via M. Santo	1,30	1,30	0,33	267	46,0	54,0	26,1

All chosen sidewalks sections have LOS A, calculated by HCM method (TRB, 2010).

3. Data collection

Surveys are performed with concealed camcorder to not influence the spontaneous pedestrians behaviour. Each site is video recordered for three hours, in the shops opening hours and on days with good weather conditions. Only the two consecutive hours with the most intense pedestrian flow are considered. For each sidewalk some signs are drawn perpendicular to the path as a reference section and measured. The time taken by each pedestrian to cross the sidewalk section was defined through video processing, based on a grid of lines on the basis of the reference signs and considering that 1 movie frame corresponds to 1/25 of second. Speed is calculated from the moment where the pedestrian entered at the moment where the pedestrian left the sidewalk section of known length. For each pedestrian data are collected: gender, age, electronic devices use, bulky item carried, disability, pushchairs, direction, etc..
Pedestrians age are determined subjectively by an operator and, to reduce the error in age estimation, pedestrians are cataloged in five categories; pedestrians are also distinguished by user type in: isolated pedestrians, single pedestrians and groups. The first is a pedestrian walking alone with no one in the section, the second is a pedestrian walking alone but with others in the section and the third is a group of pedestrians walking together.

4. Data reduction

Pedestrians characterized by interference influencing their behaviour (disabilities, pushchairs, carried loads, etc..) are excluded from dataset.
Speeds analysis shows that pedestrians speeds can be approximated by a normal distribution. In fact, the area under the normal distribution graph for a distance from the mean of $\pm 3\sigma$ is 0.9973. Thus the probability that data fall within this range is 99.73% and only 0.27% of data are excluded (Montgomery 2012). This is important because the focus of the study is to determine the average pedestrian behaviour: the construction of a normal distribution of pedestrian speeds was made and data outside the range $[\mu-3\sigma; \mu+3\sigma]$ were eliminated.
Excluding data refer pedestrians with abnormal behaviour during the journey, for example people who suddenly stop and than resume walking for many reasons, joggers, runners, etc..

5. Methodology

Data are processed in order to obtain mathematical models describing the average behavior of pedestrians.
For each user type, some models are developed using multiple regression in which the dependent variable is related to independent variables by the general equation:

$$Y= \beta_0+ \beta_1 X_1+ \beta_2 X_2+ \ldots + \beta_n X_n +\varepsilon \quad (1)$$

Where; Y: is the dependent variable, $X_1,\ldots,X_n$: are independent variables, β_0: is the constant parameter (intercept), $\beta_1,\ldots, \beta_n$: are model parameters (regression coefficients), ε: is the error component in the model.
To define variables belonging to each model, the backward elimination of not significant variables (p-value>5%) are used.
The methodology used is the Cross Validation, in which a single sidewalk dataset for time are excluded; with the remaining data a behavioural model is constructed (named *partial model*); later, with the dataset excluded from the construction phase, each model is validated.
Each partial model is verified calculating the R^2 (coefficient of determination) and the RMSPE (Root mean square percent error). In the model construction phase, observed and simulated speeds have a good agreement if, graphically, data lie roughly on a 45 degree line. Later, the partial model was validated, using the sidewalk dataset excluded from the construction phase, calculating the coefficient of determination R_v^2 and $RMSPE_v$. Also in the model validation phase, observed and predicted speeds have a good agreement if, graphically, data lie roughly on a 45 degree line.
If all partial models provide good results, a global model is constructed using all sidewalks dataset and R^2 and RMSPE of this global model are calculated; also in this case, observed and predicted speeds have a good agreement if, graphically, data lie roughly on a 45 degree line.
If the global model has the same trend as partial models and partial models parameters always fall within of confidence intervals of respective global model parameters, then the partial model is considered reliable.

5.1. Variables

The speed is the variable most used in reference studies and it is the best indicator of pedestrians behaviour.
The speed is closely influenced by factors related to pedestrian and path characteristics; in particular the age is the best indicator of psycho-physical pedestrian characteristics and of his skill to walk, while the building face characterizes the path and, therefore, the environment passed through.
Dependent variables Y are:

- Y1 = mean walking speed for each age class [m/s],
- Y2 = mean walking speed for each age class according pedestrians gender [m/s].

Independent variables X_n are:

- X1= age classes for each sidewalk. The classes are: 1- From 0 to 18 years old; 2 - From 19 to 40 years old; 3 - from 41 to 65 years old; 4 - From 66 to 75 years old; 5 - Over 75 years old,
- X12= the square age classes,
- X2= the facing type: 0 - blind; 1 - accesses; 2 - shop windows,
- X3= pedestrians gender: 0 - female; 1 - male.

Also other independent variables are investigated and subsequently excluded by backward elimination like width section, effective walkway width, obstacles percentage, time of day, pedestrian flow, groups percentage, pedestrians direction.
Age class from 0 to 18 years data are present in very low percentages and therefore are excluded.

5.2. Models for isolated pedestrians

Isolated pedestrians move individually and have no interactions with other pedestrians.
By means of the multiple regression, partial models are constructed and later validated.
Two models have been identified:

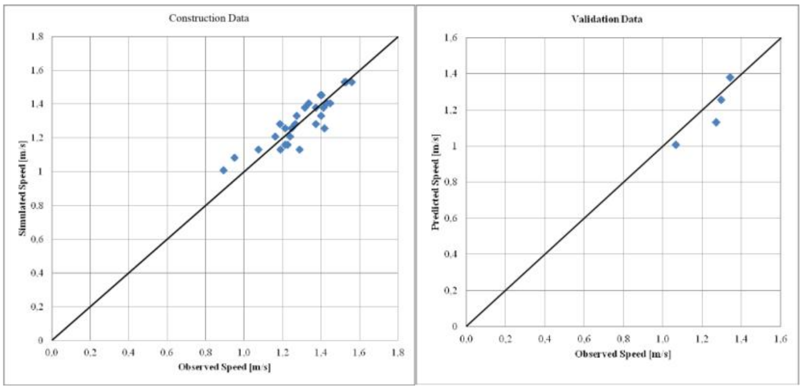
1) The mean walking speed (Y_1) is expressed as a function of age classes (X_1) and facing type (X_2),
2) The mean walking speed (Y_2) is expressed as a function of age classes (X_1), facing type (X_2) and gender (X_3).

5.2.1. Relation among mean walking speed, age classes and facing type

To better understand, results of the construction and validation phases of the partial model, obtained by excluding the sidewalk of Via Paoli sez.1, are shown as an example:

$$Y_1 = 1{,}7769 - 0{,}1237\ X_1 - 0{,}0752\ X_2 \tag{2}$$

With: R^2= 0,79; RMSPE = 0,0607. Validation phase: R^2v= 0,81; $RMSPE_v$ = 0,0652.



(1a) (1b)

Fig. 1.
Partial model excluding sidewalk of Via Paoli sez.1. Comparison between observed and estimated dataset: construction phase (1a); validation phase (1b)

Coefficients of determination and RMSPE indexes have good values, in addition observed and estimated speeds have a good agreement.
Excluding other sidewalks one at a time, similar results are obtained.
Thus, using all the sidewalks data at the same time, a global model was constructed:

$$Y_1 = 1{,}7522 - 0{,}1169\ X_1 - 0{,}0674\ X_2 \tag{3}$$

With: R^2= 0,77; RMSPE = 0,0624.

Table 2
Global Model: Regression statistics and ANOVA

Regression Statistics						
Multiple R	0,879398	--	--	--	--	--
R Square	0,773341	--	--	--	--	--
Adjusted R Square	0,75771	--	--	--	--	--
Standard Error	0,076153	--	--	--	--	--
Observation	32	--	--	--	--	--
Analysis of Variance						
Variable	**df**	**SQ**	**MQ**	**F**	**Significance F**	
Regression	2	0,573811	0,286905	49,47285	4,5E-10	--
Residual	29	0,168178	0,005799	--	--	--
Total	31	0,741989	--	--	--	--
	Coeff.	**Standard Error**	**t Stat**	**P-Value**	**Lower 95%**	**Upper 95%**
Intercept	1,752226	0,048316	36,26633	1,03E-25	1,65341	1,851043
(X_1) Age Class	-0,11686	0,012902	-9,05795	5,93E-10	-0,14325	-0,09048
(X_2) Facing Type	-0,0674	0,015325	-4,398	0,000135	-0,09874	-0,03606

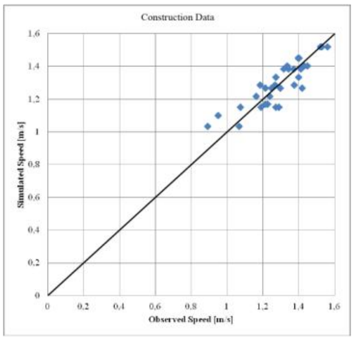


Fig. 2.
Global Model. Comparison between observed and simulated speeds

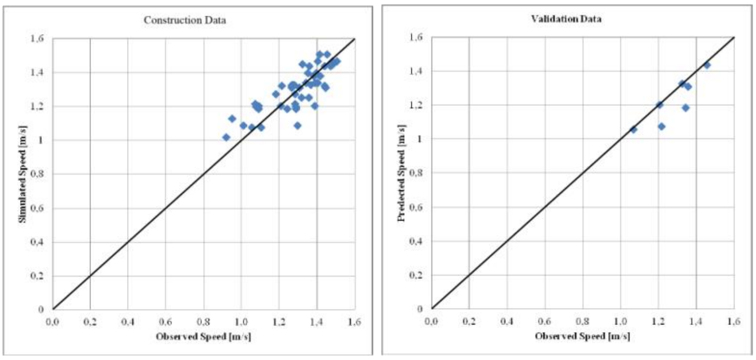
The global model has the same trend as partial models, partial models parameters always fall within of confidence intervals of respective global model parameters; coefficient of determination and RMSPE index have good values; in addition observed and estimated speeds have a good agreement in fact they roughly lie on a 45 degree line; then the partial model is considered reliable.

5.2.2. Relation among mean walking speed, age classes, facing type and gender

To better understand, results of the construction and validation phases of the partial model, obtained by excluding the sidewalk of Via Paoli sez.1, is shown as an example:

$$Y_2 = 1{,}7188 - 0{,}1264\ X_1 - 0{,}0693\ X_2 - 0{,}1089\ X_3 \tag{4}$$

With: R^2= 0,74; RMSPE = 0,0683. Validation phase: R^2v= 0,76; $RMSPE_v$ = 0,0647.



(3a) (3b)

Fig. 3.
Partial model excluding sidewalk of Via Paoli sez.1. Comparison between observed and estimated dataset: construction phase (3a); validation phase (3b)

Coefficients of determination and RMSPE indexes have good values, in addition observed and estimated speeds have a good agreement.
Excluding other sidewalks one at a time, similar results are obtained.
Thus, using all the sidewalks data at the same time, a global model was constructed:

$$Y_2 = 1{,}6999 - 0{,}1214\ X_1 - 0{,}0605\ X_2 + 1099\ X_3 \tag{5}$$

With: R^2= 0,73; RMSPE = 0,0684.

Table 3
Global Model: Regression statistics and ANOVA

Regression Statistics						
Multiple R	0,851898	--	--	--	--	--
R Square	0,72573	--	--	--	--	--
Adjusted R	0,710205	--	--	--	--	--
Standard Error	0,085461	--	--	--	--	--
Observation	57	--	--	--	--	--
Analysis of Variance						
Variable	**df**	**SQ**	**MQ**	**F**	**Significance F**	
Regression	3	1,02425	0,341417	46,74671	6,53E-15	--
Residual	53	0,387088	0,007304	--	--	--
Total	56	1,411338	--	--	--	--
	Coeff.	**Standard Error**	**t Stat**	**P-Value**	**Lower 95%**	**Upper 95%**
Intercept	1,699911	0,042397	40,09515	2,52E-41	1,614874	1,784949
(X_1) Age Class	-0,1214	0,011338	-10,7071	7,31E-15	-0,14414	-0,09866
(X_2) Facing Type	-0,06048	0,012872	-4,69836	1,9E-05	-0,0863	-0,03466
(X_3) Gender	0,109945	0,022826	4,816716	1,26E-05	0,064162	0,155728

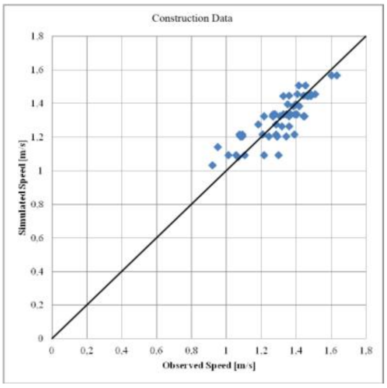


Fig. 4.
Global Model. Comparison between observed and simulated speeds

The global model has the same trend as partial models, partial models parameters always fall within of confidence intervals of respective global model parameters; coefficient of determination and RMSPE index has good value, in addition observed and estimated speeds roughly lie on a 45 degree line.

5.3. Models for single pedestrians

The single pedestrians move alone within the pedestrian flow and have interactions with other pedestrians who walk in the same or opposite direction.
By means of the multiple regression partial models are constructed and later validated.
Two models have been identified:

1) the mean walking speed (Y_1) is expressed as a function of the square of age classes (X_1) and facing type (X_2),

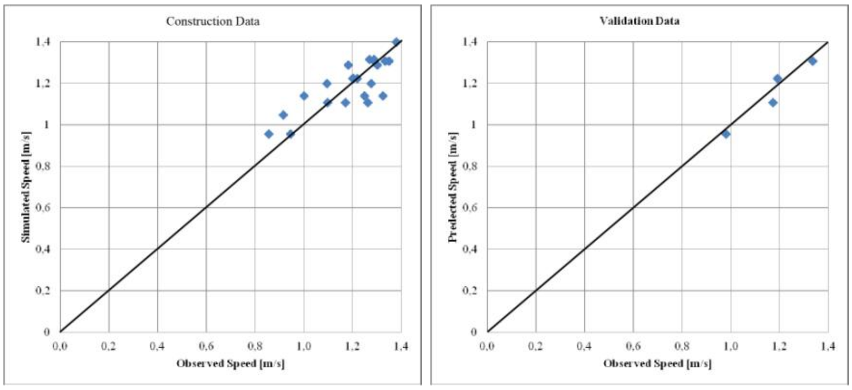
2) the mean walking speed (Y_2) is expressed as a function of the square of age classes (X_1), facing type (X_2) and gender (X_3).

5.3.1. Relation among mean walking speed, age classes and facing type

To better understand, results of the construction and validation phases of the partial model, obtained by excluding the sidewalk of Via Paoli sez.1, is shown as an example:

$$Y_1 = 1{,}5564 - 0{,}0167\, X_1^2 - 0{,}0909 X_2 \tag{6}$$

With: R^2= 0,76 e RMSPE= 0,0696. Validazione phase: R^2_v= 0,93 e $RMSPE_v$= 0,0354.



(5a) (5b)

Fig. 5.
Partial model excluding sidewalk of Via Paoli sez.1. Comparison between observed and estimated dataset: construction phase (5a); validation phase (5b)

Coefficients of determination and RMSPE indexes have good values, in addition observed and estimated speeds have a good agreement.
Excluding other sidewalks one at a time, similar results are obtained.
Thus, using all the sidewalks data at the same time, a global model was constructed:

$$Y_1 = 1{,}5531 - 0{,}0165\, X_1^2 - 0{,}0878\, X^2 \tag{7}$$

With: R^2= 0,78; RMSPE=0,0669.

Table 4
Global Model: Regression statistics and ANOVA

Regression Statistics						
Multiple R	0,881142	--	--	--	--	--
R Square	0,776411	--	--	--	--	--
Adjusted R	0,761986	--	--	--	--	--
Standard Error	0,08138	--	--	--	--	--
Observation	34	--	--	--	--	--
Analysis of Variance						
Variable	**df**	**SQ**	**MQ**	**F**	**Significance F**	
Regression	2	0,712914	0,356457	53,82367	8,25E-11	--
Residual	31	0,205303	0,006623	--	--	--
Total	33	0,918217	--	--	--	--
	Coeff.	**Standard Error**	**t Stat**	**P-Value**	**Lower 95%**	**Upper 95%**
Intercept	1,553102	0,032839	47,29409	1,82E-30	1,486126	1,620078
(X_1^2) Age Class^2	-0,01651	0,001839	-8,97392	3,98E-10	-0,02026	-0,01275
(X_2) Facing Type	-0,0878	0,015752	-5,57404	4,14E-06	-0,11993	-0,05568

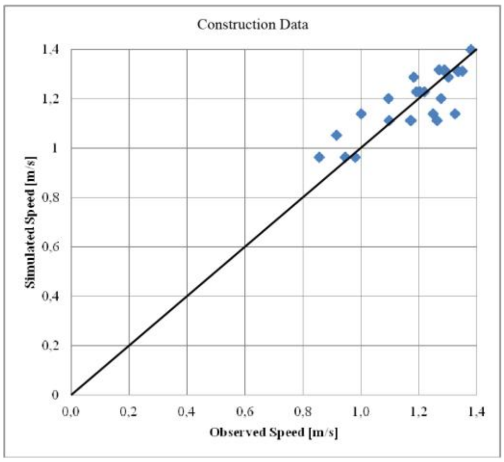


Fig. 6.
Global Model. Comparison between observed and simulated speeds

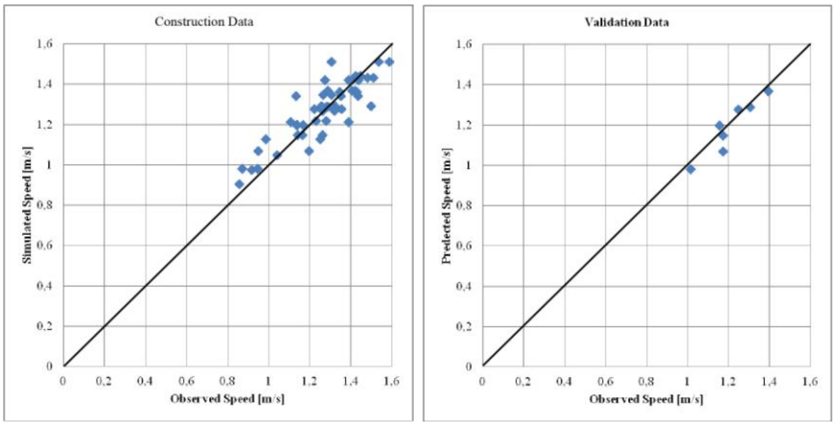
The global model has the same trend as partial models, partial models parameters always fall within of confidence intervals of respective global model parameters; coefficient of determination and RMSPE index has good value, in addition observed and estimated speeds fact they roughly lie on a 45 degree line.

5.3.2. Relation among mean walking speed, age classes, facing type and gender

To better understand, results of the construction and validation phases of the partial model, obtained by excluding the sidewalk of Via Paoli sez.1, is shown as an example:

$$Y_2 = 1{,}5101 - 0{,}0187\, X_1^{2} - 0{,}0755\, X_2 - 0{,}0803\, X_3 \qquad (8)$$

With: R^2= 0,76 e RMSPE= 0,0698. Validation phase: R^2_v= 0,88 e $RMSPE_v$= 0,0414.



(7a) (7b)

Fig. 7.
Partial model excluding sidewalk of Via Paoli sez.1. Comparison between observed and estimated dataset: construction phase (7a); validation phase (7b)

Coefficients of determination and RMSPE indexes have good values, in addition observed and estimated speeds have a good agreement.

Excluding other sidewalks one at a time, similar results are obtained.

Thus, using all the sidewalks data at the same time, a global model was constructed:

$$Y_2 = 1{,}5354 - 0{,}0191\, X_1^{2} - 0{,}0830\, X_2 + 0{,}0783\, X_3 \qquad (9)$$

With: R^2 = 0,82; RMSPE = 0,0596.

Table 5
Global Model: Regression statistics and ANOVA

Regression Statistics						
Multiple R	0,905187	--	--	--	--	--
R Square	0,819363	--	--	--	--	--
Adjusted R	0,808942	--	--	--	--	--
Standard Error	0,074541	--	--	--	--	--
Observation	56	--	--	--	--	--
Analysis of Variance						
Variable	**df**	**SQ**	**MQ**	**F**	**Significance F**	
Regression	3	1,310593	0,436864	78,62342	2,52E-19	--
Residual	52	0,288934	0,005556	--	--	--
Total	55	1,599526	--	--	--	--
	Coeff.	**Standard Error**	**t Stat**	**P-Value**	**Lower 95%**	**Upper 95%**
Intercept	1,535384	0,025014	61,38175	3,37E-50	1,48519	1,585578
(X_1^2) Age Class^2	-0,01912	0,001419	-13,4676	1,38E-18	-0,02197	-0,01627
(X_2) Facing Type	-0,08303	0,011298	-7,34962	1,37E-09	-0,1057	-0,06036
(X_3) Gender	0,078262	0,0202	3,874327	0,000301	0,037727	0,118796

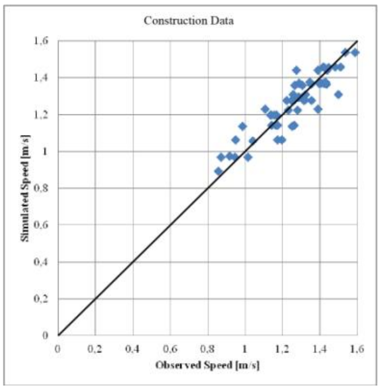


Fig. 8.
Global Model. Comparison between observed and simulated speeds

The global model has the same trend as partial models, partial models parameters always fall within of confidence intervals of respective global model parameters; coefficient of determination and RMSPE index has good value, in addition observed and estimated speeds roughly lie on a 45 degree line.

5.4. Models for groups

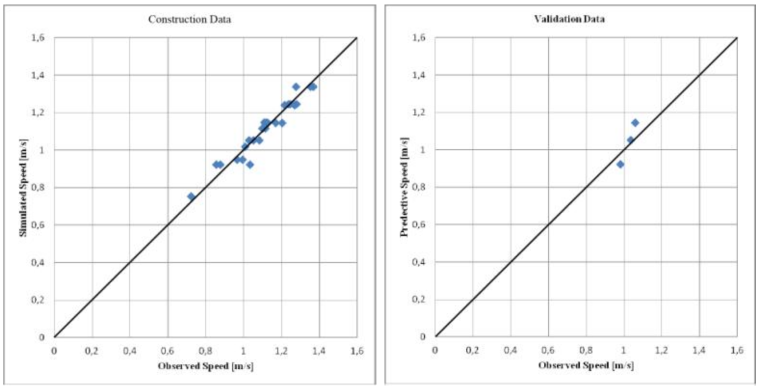
Pedestrians in group always move together with other pedestrians (one or more).
Their speeds are influenced by group size and interactions with other pedestrians constituting the pedestrian flow.
Only a model is identified; the mean walking speed (Y_1) is expressed as a function of age classes (X_1) and the facing type (X_2).
For this user type, the model expressed also as a function of gender was not good because the gender variable losts significance.

5.4.1. Relation among mean walking speed, age classes and facing type

By means of the multiple regression partial models are constructed and later validated.
To better understand, results of the construction and validation phases of the partial model, obtained by excluding the sidewalk of Via Paoli sez.1, is shown as an example:

$$Y_1 = 1{,}4124 - 0{,}0186\ X_1^2 - 0{,}0969\ X_2 \qquad (10)$$

With: R^2= 0,93 e RMSPE= 0,0375. Validation phase: R^2_v= 0,98 e $RMSPE_v$= 0,0586.



(9a) (9b)

Fig. 9.
Partial model excluding sidewalk of Via Paoli sez.1. Comparison between observed and estimated dataset: construction phase (9a); validation phase (9b)

Coefficients of determination and RMSPE indexes have good values, in addition observed and estimated speeds have a good agreement.
Excluding other sidewalks one at a time, similar results are obtained.
Thus, using all the sidewalks data at the same time, a global model was constructed:

$$Y_1 = 1{,}4042 - 0{,}0179\ X_1^{\ 2} - 0{,}0980\ X_2 \tag{11}$$

With: R^2= 0,92 e RMSPE=0,0400.

Table 6
Global Model: Regression statistics and ANOVA

Regression Statistics						
Multiple R	0,959439	--	--	--	--	--
R Square	0,920523	--	--	--	--	--
Adjusted R Square	0,91441	--	--	--	--	--
Standard Error	0,043519	--	--	--	--	--
Observation	29	--	--	--	--	--
			Analysis of Variance			
Variable	**df**	**SQ**	**MQ**	**F**	**Significance F**	
Regression	2	0,57034	0,28517	150,5698	5,05E-15	--
Residual	26	0,049242	0,001894	--	--	--
Total	28	0,619582	--	--	--	--
	Coeff.	**Standard Error**	**t Stat**	**P-Value**	**Lower 95%**	**Upper 95%**
Intercept	1,40423	0,019192	73,16787	1,22E-31	1,364781	1,44368
(X_1^2) Age Class^2	-0,01788	0,00123	-14,5316	5,4E-14	-0,02041	-0,01535
(X_2) Facing Type	-0,09804	0,008958	-10,9452	3,13E-11	-0,11646	-0,07963

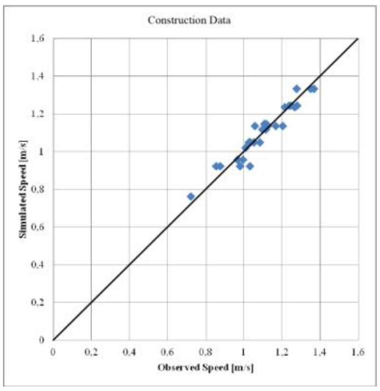


Fig. 10.
Global Model. Comparison between observed and simulated speeds

The global model has the same trend as partial models, partial models parameters always fall within of confidence intervals of respective global model parameters; coefficient of determination and RMSPE index has good value, in addition observed and estimated speeds roughly lie on a 45 degree line.

6. Conclusions

The paper purpose is to study the average pedestrians behaviour, according to pedestrians and paths characteristics. For this reason, pedestrians are subdivided into user types: isolated pedestrians, single pedestrians and groups.
For each type of user, models emphasize variations in the mean walking speed as a function of independent variables like age group, gender and facing type.
For user type "isolated pedestrians", in the first model the mean walking speed linearly decreases with increasing age class and facing type; while in the second model the mean walking speed linearly decreases with increasing age class and facing type and increases with gender.
For user type "single pedestrians", in the first model the mean walking speed decreases with square age class and facing type; while in the second model the mean walking speed decreases with square age class and facing type and grows with gender.
Only one model is found for user type "groups”; the mean walking speed decreases with square age class and facing type; no relationship is found between the mean walking speed and the gender because it loses statistical significance.
In general, the mean walking speed decreases with age classes: this confirms that with increasing age decrease psycho-physical pedestrians characteristics and therefore their walking ability.
The mean walking speed is also influenced by facing type, then the environment passed through: in fact lower speeds are obtained in presence of shops windows while higher speeds are obtained with blind overlooking; finally male pedestrians are faster than female.
The mean walking speed of “isolated pedestrians” are, generally, higher than those of “single pedestrians” and “groups”, the latter instead assume the lowest values. In “isolated pedestrians” the variable age class is in linear form, while in “single pedestrians” and “groups” is in quadratic form. This is because the "isolated pedestrians" behaviour don't suffer influences of other pedestrians, while in "single pedestrians" interactions with other pedestrians, walking in the same direction or opposite, have influences on speed and route. These influences are stronger in the “groups”. The speed of a pedestrian within a group is mainly influenced by the speed of pedestrians walking together (for this reason the gender variable loses statistical significance).
The literature, to the present day, mainly investigates the free-flow speed, ie, only isolated pedestrians, not taking into account other types of pedestrians who have more interference and influences, both with the other pedestrians and with the environment; for this reason the other types of users deserve to be more closely investigated. Such characteristics are absent in the “isolated pedestrians” but affect the other user types behaviour.
These results could improve pedestrian behaviour research and be useful to planning and design urban area, also in other cities with similar characteristics.

References

Finnis, K.K; Walton, D. 2007. Field observations of factors influencing walking speed. In: *2nd International Conference Proceedings on Sustainability Engineering and Science*, Auckland, New Zealand (NZ), Feb 21-23, 2007. Available from Internet: < http://www.thesustainabilitysociety.org.nz >.
TRB 2010. *Highway Capacity Manual*, National Research Council, Washington D.C., U.S.A.
Montgomery, D.C.; Runger, G.C.; Hubele, N.F. 2012. *Statistica per ingegneria*. EGEA, Milano, Italy.
Murrau, R.; Pinna, F. 2014. Pedestrian behavior in urban area. In *Proceedings of the Second International Conference on Ttraffic and Transport Engineering*, 772-779.
Nazir, M.I.; Al Razi, K.M.A; Hossain, Q.S.; Adhikary, S.K. 2014. Pedestrian flow characteristics at walkways in Rajshahi Metropolitan City of Bangladesh. In *Proceedings of the 2nd International Conference on Civil Engineering for sustainable Development (ICCESD-2014).*
Rahman, K.; Ghani, N.A.; Kamil, A.A.; Mustafa, A. 2012. Analysis of pedestrian free flow walking speed in a least developing country: A factorial design study, *Research Journal of Applied Sciences, Engineering and technology*, 4(21):4299-4304.
Willis, A.; Gjersoe, N.; Havard, C.; Kerridge, J.; Kukla, R. 2004. Human movement behaviour in urban spaces: implications for the design and modelling of effective pedestrian environments, *Environment and Planning B: Planning and Design*, 31: 805-828.

PEDESTRIAN CROSSING BEHAVIOUR IN MIXED TRAFFIC

Ranja Bandyopadhyaya[1], Chandan Kumar[2]
[1,2] National Institute of Technology, Patna, India

Abstract: Road crossing behaviour of pedestrians is a widely researched topic. Researchers have modelled pedestrian time gap acceptance and waiting times mostly as controlled experiments and in uniform traffic conditions. In developing countries, urban traffic comprises of motorized and non-motorized vehicles plying at widely varying speeds. Modelling pedestrian crossing behaviour in such mixed traffic conditions and also when pedestrian's mind is diverted using a mobile phone is difficult and limited research has been done in this area. In this work pedestrian crossing behaviour is studied in mixed traffic conditions for one-way traffic in the city of Patna, India using a video camera. It was observed that time gap acceptance decreases when the person is using a mobile phone while crossing. Also, pedestrians tend to cross in meandering trajectory when on mobile phone or when encountering non-motorized low speed vehicles.

Keywords: pedestrian crossing, mixed traffic, meandering crossing, crossing with phone.

1. Introduction

The road crossing behaviour of pedestrians in terms of their vehicle time gap acceptance and waiting times for different vehicle approach speeds have been widely studied by researchers.Pedestrian crossing behaviour depends on a range of factors. Researchers have tried to investigate the effect of age, gender, trip purpose, traffic speed and alertness level on crossing behaviour of pedestrians. Most of these studies have been done as controlled experiments and in uniform traffic conditions.

Holland and Hill (2007) found that women are more cautious and are less likely to cross when there is a high perception of risk than men while crossing streets.Havard& Willis (2012) observed that older pedestrians have a tendency to be more cautious than younger adults when accepting traffic gaps while crossing. They also found that the children make fewer appropriate safe crossing decisions than teenagers or adults. Similar observations were made by Bernhoft and Carstensen (2008) in a questionnaire based survey of pedestrians and cyclists in Denmark. They found that the older respondents appreciate significantly safer facilities (zebras, signalized intersections, cycle paths) than the younger respondents. They also found that younger pedestrians choose the fastest alternative while crossing, while the older road users tend to choose the safest facility and gap while crossing.

In an observational study of pedestrians performed at an unmarked roadway in China, Zhuang& Wu (2011), found that pedestrians prefer to cross a road actively in cautious ways rather than waiting passively. It may be mentioned here that in most small Indian cities pedestrians cross actively at mid block sections by waiting for acceptable gap or headway. Gastadi et al. (2015) tried to model pedestrian gap acceptance with logit and fuzzy models. Kadali &Vedagiri (2013) studied pedestrian critical gap acceptance behaviour at a six-lane, divided, mid-block section in Worli, Mumbai, India.

Many researchers have focused on studying the effect of mental alertness of pedestrians on their crossing behaviour. Haga et al. (2015) conducted a controlled experiment to examine the effect of use of smart-phone while walking . The participants texted, watched video and played games while crossing. Results showed that lack of alertness caused participants to choose lower gaps for crossing. Many similar studies (Nasar et al., 2008; Chen, 2013) show that pedestrian crossing and walking behaviour is altered and affected by the level of mental alertness.

In developing countries, the urban traffic is usually a mix of motorized vehicles like two-wheelers, cars, buses and heavy vehicles and non motorized vehicles like bicycles and rickshaws. The pedestrians while crossing the road usually encounters a number of such different types of vehicles plying at different speeds. Sometimes the pedestrian walks and crosses straight or in a weaving trajectory and sometimes runs partially through the section. Modelling pedestrian crossing behaviour in terms of gap acceptance in mixed traffic and its effect while the pedestrian's mind is diverted using a mobile phone,luggage orother heavy object is a challenging task and limited research has been done in this area. In this work pedestrian crossing behaviour is studied in mixed traffic condition for one-way traffic. An attempt is also made to study the effect of use of mobile phones on the time gap acceptance of pedestrians crossing roads having mixed traffic at different approach speeds.

The main objectives of the study are

- To check the behaviour of the pedestrian using and not using the mobile phone in mixed traffic condition for one-way traffic.
- To study the effect of use of mobile phones on the time gap acceptance of pedestrian crossing at different approach speeds and vehicle types.
- Relation between the gap acceptance, time to cross and waiting time of a pedestrian.

The nextsection details the methodology adopted for the work. Section 3 details the data and data collection techniques. Section 4 details the analysis and results and section 5 gives the major conclusions that may be drawn from the work.

[1] Corresponding author: b_ranja@yahoo.co.in

2. Methodology

The overall methodology of the work can be summarized as in **Error! Reference source not found.**. The pedestrian crossing video is taken for 5 days, for 1 hour each day in the peak hour. User data of use of mobile phone, crossing speed, crossing speed range (walking slowly, normally and running), waiting time for acceptable time gap and time gap accepted are extracted manually. The vehicle stream speed and headway are also extracted. The effect of use of mobile phone on pedestrian crossing behaviour and pedestrian gap acceptance behaviour on stream speed is analyzed.

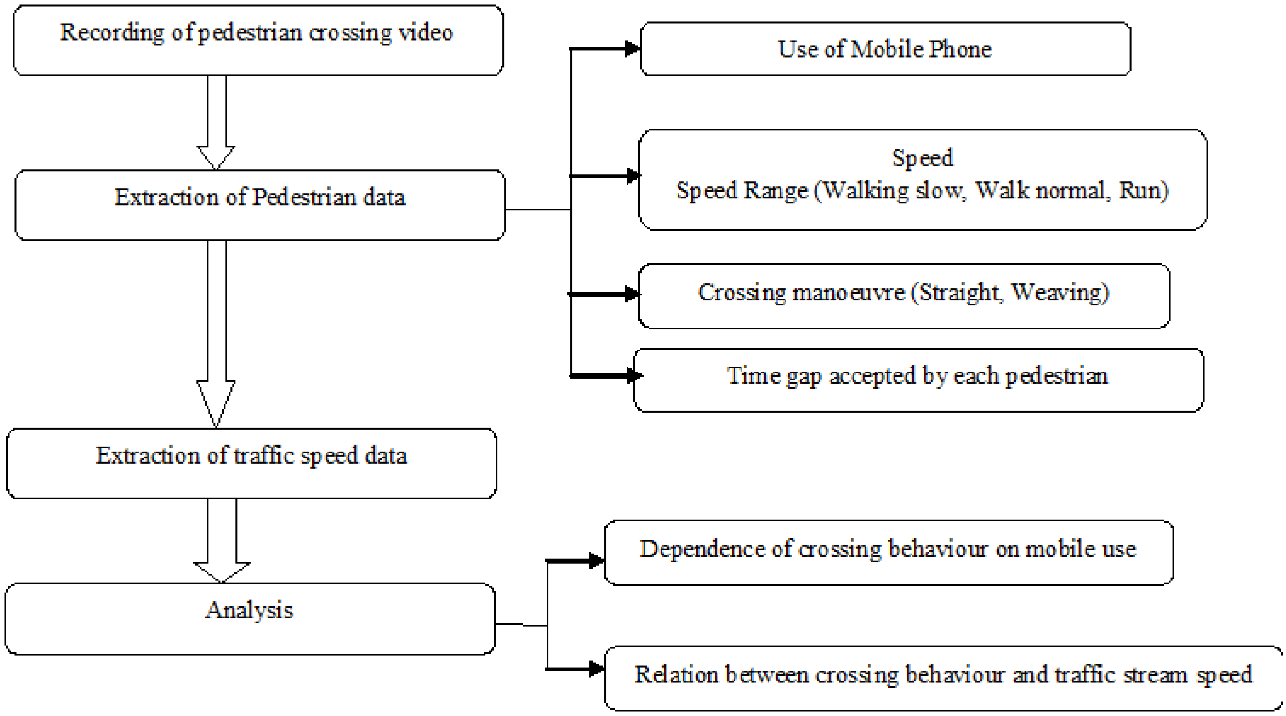


Fig. 1.
Methodology adopted for the study

3. Data

The pedestrian crossing behaviour is analysed with video data of traffic flow and pedestrian crossing through the traffic stream. The video recording is done in the Secretariat Road of Patna city, Bihar, India. The road characteristics as road width is measured manually using a tape. The road is a 4 lane divided major arterial of the Patna city carrying motorized vehicles ranging from two-wheelers and cars to buses and heavy vehicles and non-motorized vehicles like bicycles and rickshaws. The road has raised shoulders and median where pedestrians can wait for suitable gap while crossing the road. The study assumes that the pedestrian encounters traffic from only one direction. The pedestrian crosses one half of the roadand waits in the median for proper gap and crosses the other half. The width of one half of the road is 3.5 metres.

Five day 1 hour video recording of pedestrian crossing is taken during peak hour more pedestrians are crossing the road. The video is analyzed manually. The data extracted from the video recording is summarized in Table 1.

Table 1
Data Summary

SlNo.	Variable name	Unit	Min	Max	Mean	Standard Deviation
1	Waiting time	Sec	2.5	44	20	15
2	Crossing speed	m/s	0.4	1.8	0.6	0.2
3	Time gap accepted	Sec	4	16	8	1.5
4	Crossing Speed Type	Slow Walking (0.4 – 1 m/s) Walking Normally (1 – 1.5 m/s) Running (> 1.5 m/s)				
5	Use of Mobile Phone	Yes or No				
6	Crossing manoeuvre	Straight or Weaving				
7	Vehicle stream speed	m/s	8	16	12.5	2

4. Analysis & Results

The crossing behaviour is usually quantified as the time gap or time headway between two vehicles accepted by pedestrians to cross the road at mid-block sections where pedestrian crossing signals are not available. The waiting time or the time the pedestrian waits for availability of proper gap for crossing the road is also a function of the gap availability and speed of the traffic. The time gap accepted depends on the speed of the traffic stream. The crossing speed, which is another important parameter, also depends on the availability of gap and traffic speed. The crossing speed and manoeuvre depends on the mental alertness of the pedestrian and may be affected by use of mobile phone while crossing.

Initially the effect of using mobile phones on crossing behaviour of pedestrians while crossing the road actively by searching for appropriate gap is analysed. This is similar to a situation when the pedestrian is doing multiple task while crossing and is partially alert. The crossing behaviour is quantified in terms of crossing manoeuvre and crossing speed while crossing actively through traffic. The dependence of crossing behaviour of pedestrians when crossing freely and when crossing while using mobile phone is studied with chi square test of independence.

The effect of use of mobile phoneon crossing manoeuvre is a analyzed with the following two hypotheses:

Null Hypothesis H0: There is no relationship between Crossing manoeuvre and using mobile phone while crossing.

Alternative Hypothesis H1: There is a relationship between Crossing manoeuvre and using mobile phone while crossing**.**

Table 2
Use of mobile phone & crossing manoeuvre

Using mobile phone	Straight crossing	Weaving crossing
yes	169	55
no	170	840

Chi-square test of independence is done to check the hypothesis with the feedback obtained from questionnaire survey in MS EXCEL.The p-value obtained is 0.0001 which is less than the significance level of 0.05. The null hypothesis may thus be rejected.This shows that there is a significant relationship between crossing manoeuvre and carrying heavy object or mobile phone while crossing.

The effect of use of mobile phone on crossing speed is a analyzed with the following two hypotheses:

Null Hypothesis H0: There is no relationship between Crossing speed and using mobile phone while crossing.

Alternative Hypothesis H1: There is a relationship between Crossing speed and using mobile phone while crossing.

Table 3
Use of mobile phone and pedestrian crossing speed range

Pedestrian crossing speed (km/hr)		Range		
		Very slow	Walk normally	Run
Using mobile	yes	18	83	122
	no	13	60	137

Chi-square test of independence is done to check the hypothesis with the feedback obtained from questionnaire survey in MS EXCEL.The p-value obtained is 0.08 which is greater than the significance level of 0.05. The null hypothesis may thus be not being rejected.This shows that there is no significant relationship between crossing speed and using mobile phone while crossing.

Since no significant dependence could be observed between crossing speed and use of mobile phone in this study, relationship between crossing speed and choice of time gap, and relationship between crossing speed and oncoming vehicle speed are analyzed. Fig. 1. shows the relationship between crossing speed and time gap chosen for crossing. It can be observed that the crossing speed decreases with the increase of availability of time gap. This is obvious that the more the time headway available the people can walk in relaxed mode while crossing the road.

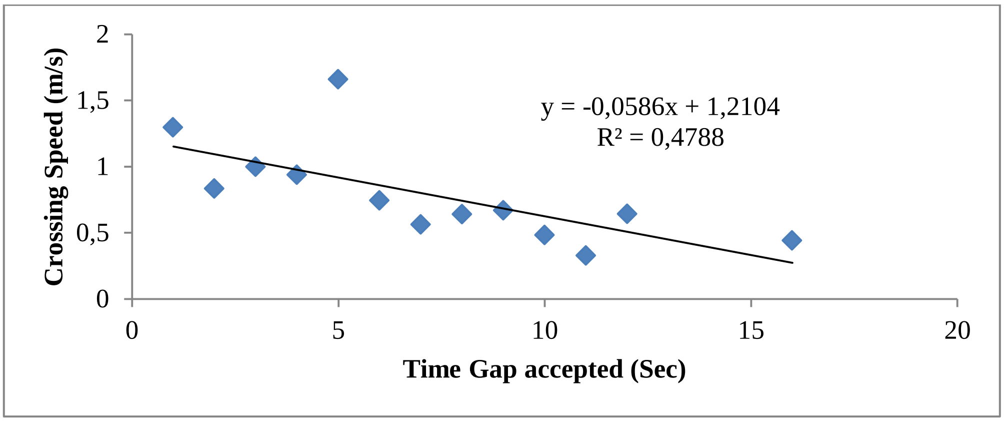


Fig. 1.
Co-relation of Time gap chosen and Crossing speed

Fig. 2. shows the relationship between crossing speed and vehicle stream speed. It can be observed that the crossing speed increases with the increase of vehicle stream speed. This is obvious that a person will speed up while crossing the road if the speed of approaching vehicles increases.

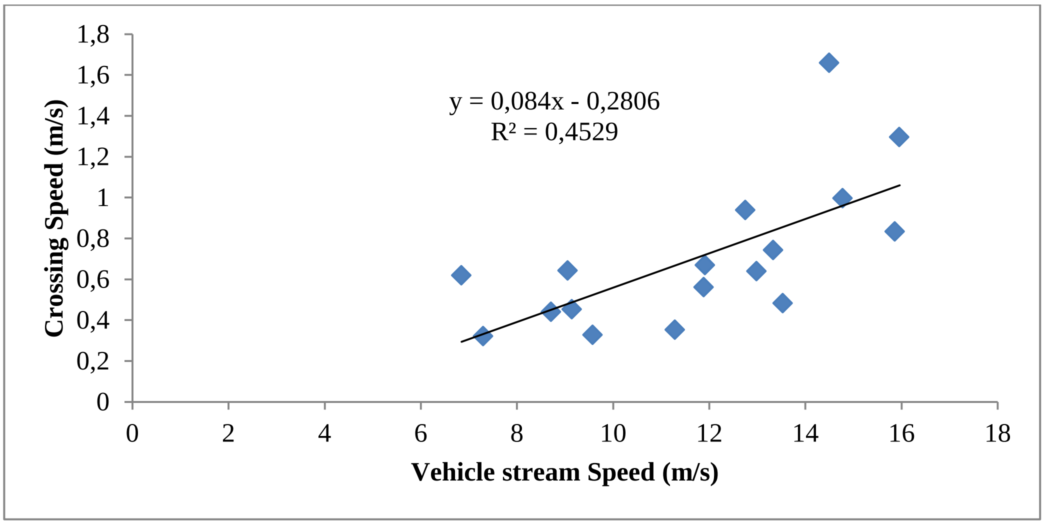


Fig. 2.
Co-relation of Vehicle stream speed and Crossing speed

Linear relationship is between crossing speed and stream speed and vehicle time gap or time headway is developed and is given in equation 1.

$$V_{Crossing} = -0.027 + 0.067V_{stream} - 0.004T_{Gap} \quad (1)$$

where,
$V_{Crossing}$ is the crossing speed in m/s
V_{stream} is the stream speed in m/s
T_{Gap} is the time gap/headway in second
The R^2 value of this regression is 0.47. The variable and their significance in the correlation is given in Table 4.

Table 4
Co-relation table of Crossing Speed regression

Variable	Coefficient	p-value
Intercept	0.27	0.95
Stream Speed (m/s)	0.067	0.07
Time headway (Gap) Sec	-0.004	0.53

It can be observed that the crossing speed is significantly dependent on the vehicle stream speed at 90% confidence limit. But, the crossing speed is not significantly dependent on the time headway available for crossing.
The variation of waiting time and the time gap or time headway accepted by pedestrian to cross is studied. Fig. 3. gives relationship between waiting time of pedestrians and the time gap available to the pedestrian for crossing the road.

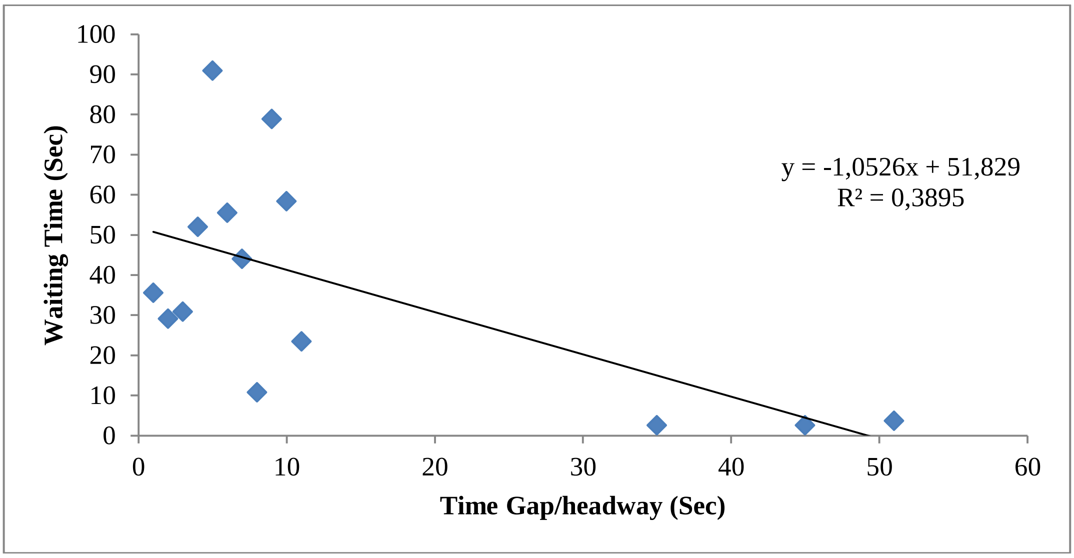


Fig. 3.
Co-relation between the waiting time & time gap accepted

It can be observed that as the time gap available to the pedestrian for crossing increases the waiting time for pedestrian for crossing the road decreases. The pedestrian can immediately start crossing the road for large time headways.
The variation of waiting time of the pedestrian to cross the road and vehicle stream speed is studied. Fig. 4. gives relationship between waiting time of pedestrians and the vehicle stream speed.

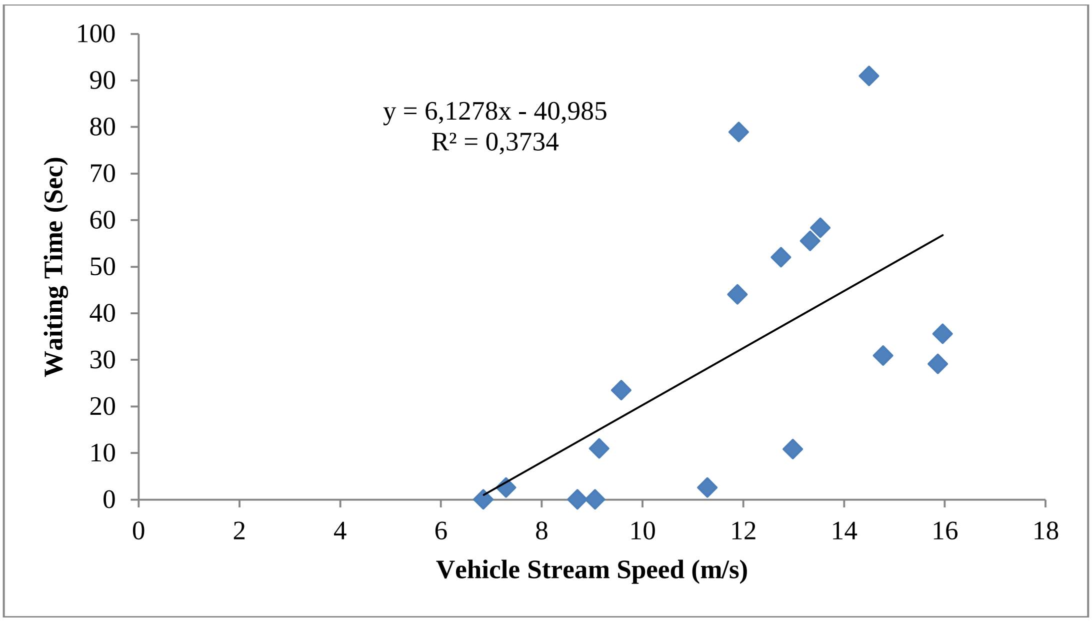


Fig. 4.
Co-relation between the waiting time & vehicle stream speed

It can be observed that as vehicle stream speed increases the waiting time for pedestrian for crossing the road increases.

5. Conclusions

The crossing behaviour is analysed in two parts. Initially, pedestrian crossing behaviour is analysed when the pedestrian is using mobile phone or carrying heavy objects. The conclusions drawn from the analysis can be summarized as:
- There is a significant relationship between crossing manoeuvre use mobile phone while crossing.
- There is no significant relationship between crossing speed of pedestrians when the pedestrian is crossing freely or is busy talking over mobile phones while crossing.

Thus, the relationship between crossing speed and traffic stream speed and relationship between time gap accepted and crossing speed is studied irrespective of the pedestrian walking free or walk while talking. The time headway accepted dependent on waiting time and vehicle speed. Thus, the variation of waiting times with time gap/headway acceptance and variation of waiting times with traffic stream speed is studied. The following conclusions may be drawn from the above study.
- The crossing speed decreases with the increase of availability of time gap. This is obvious that the more the time headway available the people can walk in relaxed mode while crossing the road.
- The crossing speed increases with the increase of vehicle stream speed. This is obvious that a person will speed up while crossing the road if the speed of approaching vehicles increases.
- The time gap available to the pedestrian for crossing increases the waiting time for pedestrian for crossing the road decreases. The pedestrian can immediately start crossing the road for large time headways.
- It can be observed that as vehicle stream speed increases the waiting time for pedestrian for crossing the road increases.

References

Bernhoft, I.M.; Carstensen, G. 2008. Preferences and behaviour of pedestrians and cyclists by age and gender, *Transportation Research Part F: Traffic Psychology and Behaviour*, 11(2): 83-95.

Chen, Y. 2013. Stress state of driver: mobile phone use while driving, *Procedia-Social and Behavioral Sciences*, *96*: 12-16.

Gastaldi, M.; Meneguzzer, C.; Gecchele, G.; Rossi, R. 2015. Comparing direct transferability of logit and fuzzy logic models of gap acceptance at unsignalized intersections, *Transportation Research Procedia*, 5: 95-102.

Haga, S.; Sano, A.; Sekine, Y.; Sato, H.; Yamaguchi, S.; Masuda, K. 2015. Effects of using a Smart Phone on Pedestrians' Attention and Walking, *Procedia Manufacturing*, 3: 2574-2580.

Holland, C.; Hill, R. 2007. The effect of age, gender and driver status on pedestrians' intentions to cross the road in risky situations, *Accident Analysis and Prevention*, 39(2): 224-237.

Havard, C.; Willis, A. 2012. Effects of installing a marked crosswalk on road crossing behaviour and perceptions of the environment, *Transportation Research Part F: Traffic Psychology and Behaviour*, 15(3): 249-260.

Kadali, B.R.; Vedagiri, P. 2013. Effect of vehicular lanes on pedestrian gap acceptance behaviour, *Procedia-Social and Behavioral Sciences*, 104: 678-687.

Nasar, J.; Hecht, P.; Wener, R. 2008. Mobile telephones, distracted attention, and pedestrian safety, Accident *Analysis & Prevention*, 40(1): 69-75.

Zhuang, X.; Wu, C. 2011. Pedestrians' crossing behaviours and safety at unmarked roadway in China, *Accident Analysis and Prevention*, 43(6): 1927-1936.

IMPACT OF ICT ON SOME SEGMENTS OF EVERYDAY LIFE OF HIGHSCHOOL POPULATION OF THE CITY OF ZAGREB

Slaven Gašparović[1]
[1] University of Zagreb, Faculty of Science, Department of Geography, Zagreb, Croatia

Abstract: Virtual mobility is defined as mobility within the virtual world which is accomplished by use of information and communication technology (ICT) in order to access certain activities without physical access that traditionally required physical access. Nowadays, young people are group of society that is most often engaged in virtual mobility and takes advantages of various opportunities that ICT provides. The paper shows that the greatest influence of ICT on the lives of high school students has on the social interactions and school activities. The aim of this paper was to investigate the impact of ICT on social interactions and school activities of high school population of the City of Zagreb. The research was conducted and analyzed using quantitative, as well as qualitative methods. The data was collected by conducting a survey on 826 high school students of the City of Zagreb. In order to make detail research of specific problems of high school population, high school students of the City of Zagreb were detiaily interviewed through eight focus groups. Thus, the results obtained from the survey were further substantiated by claims from the focus groups. The results showed significant correlation between the use of ICT and academic achievements of students. In addition, students were deeply aware of the negative impact of the internet and mobile phones usage on their school activities. Also, results showed that ICT helped in communicating with friends, but without the effect on the number of friends.

Keywords: ICT, virtual mobility, high school population, City of Zagreb.

1. Introduction

Today, young people are the group of society that is most often engaged in virtual mobility, thereby taking advantage of various opportunities provided by telecommunication and computer technology (ICT) (Livingstone, 2006; Alvarez et al., 2013). Young people use ICT technology by use of computers and mobile devices (smartphones and cell phones). Here, it should be noted that today computers and mobile phones are multi-functional as the Internet can be accessed via mobile devices (smartphones), while the former "classic" telephone conversation can be performed using a personal computer (e.g. via Skype). On the other hand, young people are transport disadvantaged social group often with limited mobility and accessibility to life activities (Gašparović, 2014; Gašparović, 2016). Therefore, young people will often use virtual mobility as a substitute for physical mobility and, under certain circumstances will reduce the impact of transport disadvantage on their everyday lives.

Croatian scientific bibliography lacks studies of interrelationship between ICT and young people thereby providing the motive for this work. Studies are mainly related to ICT as a factor of risk behavior, addiction, and violence on the Internet (e.g. Puharić et al., 2015; Mandarić, 2012; Ružić, 2011). Only rare publications address everyday life of young people (e.g. Nicodemus et al., 2014). It is important to note that there are no references regarding this subject matter on high school students.

The aim of this paper is to investigate the impact of ICT on the selected segments of high school population everyday life. The emphasis is put on the impact of ICT on the school activities of students and their social interactions. In addition, the paper studied differences in the impact of ICT on the selected segments of everyday life with regard to gender. Based on their self-assessments, the surveyed students expressed the importance of ICT in their lives. The paper presents the aspect of possible substitution of existing physical mobility for ICT and the increasing potential of ICT.

2. Theoretical framework and research methodology

Mobility can be defined from several different points of view, which results in the different types of mobility (Kenyon et al., 2002; Larsen et al., 2006). In addition to the physical movement, new types of mobility emerged and are strengthen with the development of ICT. Thus, virtual movement or virtual mobility gained on the significance. Virtual mobility is a movement in the virtual world that is realized in the context of telecommunication and computer technologies. Therefore, virtual mobility is about accessing to certain activities that traditionally required physical access, which can now be performed without physical access. This is very important issue because virtual mobility overcomes geographical and social distance in real time. Virtual mobility is strongly linked to the extreme expansion of the Internet and mobile telecommunication, completely changing the human race. Therefore, virtual mobility includes, among other things, teleworking, creating new and maintaining existing social connections (especially via the social media, e-mails and personal web pages), gaining both formal and informal education, shopping via the Internet etc. If the physical mobility is hampered or disabled for some reason, in certain circumstances virtual mobility may be used as its substitute (Kenyon et al., 2002; Larsen et al., 2006).

International scientific bibliography is extremely rich in studies about the relationship between ICT and young people. However, not so many articles concerning the high school population can be found. Also, there are only few papers describing the impact of ICT on school activities of students. The link between ICT and school activities is studied mainly from the aspect of Internet addiction and its impact on childrens' education. Further, Internet addiction was

[1] Corresponding author: slaveng@geog.pmf.hr

associated with problems in learning and school success (e.g. Siomos et al., 2013; Zhu et al., 2015; Soohyun, 2011). Badasyan and Silva (2012) have concluded that the possibility to access the Internet affected good school achievement, while Adegoke (2013) and Darah (2013) concluded that Internet access had no effect on school performance. Austin and Totaro (2011) have concluded that excessive use of the Internet adversely affected school performance. Young people use the Internet for a whole range of activities. Among the most common reasons for Internet usage are school activities and games (Omar et al., 2014; Lee and Chae, 2007). A whole range of authors emphasized communication (i.e. instant messaging and social networking) as an important reason for Internet usage (Paus-Hasebrink et al., 2010). Studies of numerous authors put the emphasis on social media usage (e.g. Woods et al., 2016; Montgomery, 2015; Barbieri, et al., 2016). The impact of mobile phones is also mentioned in both, positive and negative context. Seo et al. (2016) state that mobile phones are used for assistance in school activities, while Abeele et al. (2014) consider it as an important tool for social networking. However, many authors emphasize negative aspects of mobile phone usage, such as addiction, attention deficit, depression and so (e.g. Billieux, 2012; Lee et al., 2014), which may adversely affect the school and other activities.

In this study survey and interview methods were used. Anonymous and completely voluntary survey was conducted in seven high schools in the City of Zagreb. A total of 826 students were surveyed (3% of the total high school population in the City of Zagreb). Gender ratio in the survey included 429 females (51.9%) and 397 males (48.1%). The survey obtained general information about the participants and their attitudes and opinions towards ICT and its impact on their everyday lives. Students were also asked to give their opinions about eight suggested transport (virtual mobility) issues, according to the Likert scale, in which each issue was assessed from 1 to 5 indicating their importance for the student (on the scale: 1 – no importance/very little importance; 5 – very high importance).

In order to obtain detailed information on the researched issues, focus group method was included to the research. The focus group research was conducted in two high schools in the City of Zagreb. In each school students were divided into four groups based on their age and gender. Group I included female students of the 1st and 2nd grades, Group II male students of the 1st and 2nd grades, Group III female students of the 3rd and 4th grades, and Group IV male students of the 3rd and 4th grades. In total 8 focus groups were examined. Within each group, there was an evident dichotomy among the students with regard to their place of residence (half of the students lived near the city center and half lived nearer to the city periphery).

The research was conducted according to the *Code of Ethics of Research with Children* (2003). Permission for the research was obtained from the Ministry of Science, Education and Sport of the Republic of Croatia, the Principal of each school and pupils' parents. The data collected in the survey were processed using the software package SPSS Statistics 20.0 using the statistical correlation method and t-test.

3. Impact of ICT on some segments of everyday life of high school population

Computer technology is very widespread among young people. This is confirmed by the fact that 99% of surveyed students (818 of 826 students) in this study used a computer at home. Students used laptops and desktops almost equally, 51.5% students (421) used laptop, while used 48.5% students (397) use desktop computer. Only 1% of students (8) did not use computer at home, for being used by other family members (7 students) or not owning one (only one student). Further, the vast majority of students accessed Internet via computers at a flat rate (89%, 735 students), while 7.6% (63 students) accessed Internet with limited data traffic. Only 3.4% of students (28) did not have Internet access at home. Still, out of this 3.4%, 9 of them had possibility to access it regularly elsewhere, while 10 students had possibility to access it occasionally elsewhere. Only 9 students lacked the possibility to access Internet at home, and did not have the possibility to access it elsewhere.

Beside computer technology, mobile technology increasingly takes place in the everyday lives of young people. Thus 99.3% of students use mobile phone (820 of 826 surveyed students). 3/4 of students use a smartphone (76.7% or 629 students), while 191 of them (23.3%) use a cell phone. Only 6 students don't use a mobile phone (0.7% of the surveyed students). It should be noted that 764 students use the Internet via mobile phone (92.5% of students), while only 7.5% (62 students) students don't use it. 545 students (71.3%) use mobile Internet regularly, occasionally 166 students (21.7%), and when it is absolutely necessary 53 students (7.0%).

Numerous studies tried to determine the extent of internet usage among the students. These estimates varied in dependence of the method used for Internet usage measurement (e.g. on the basis of personal statements or automatic recording), the age of examined children and definition of "Internet usage" (e.g. time spent or frequency of use). Studies reported that young people use the Internet on average for 1 to 3 hours daily (Jackson et al., 2006; Alvarez et al., 2013). Researchers agree that children today spend a considerable amount of time using the Internet (Jackson et al., 2006; Livingstone et al., 2011; Özgür, 2016).

Due to the growing importance of the Internet in everyday life of students, which is accessed either by computers or mobile phones, the time spent on the Internet is even higher than previous reports suggest. The results showed that high school students spend 4.3 hours on the Internet on average daily (including the usage of virtual social networks). Interestingly, there was no statistically significant correlation between age and time spent on the Internet, while the slight statistically significant correlation occurred with regard to gender ($r = .117$, $p<0.01$), which was confirmed by t-test ($t = -3.389$; $p<0.01$). These results indicated that girls spend more time on the Internet than boys.Furthermore, reasons for using the Internet had to be established. Studies have shown that young people use the Internet mostly for school activities (information, homework, school projects) and communication with friends (via email and chat) (Jackson et al., 2006). Although these were recent researches, today there are other reasons for the use the Internet.

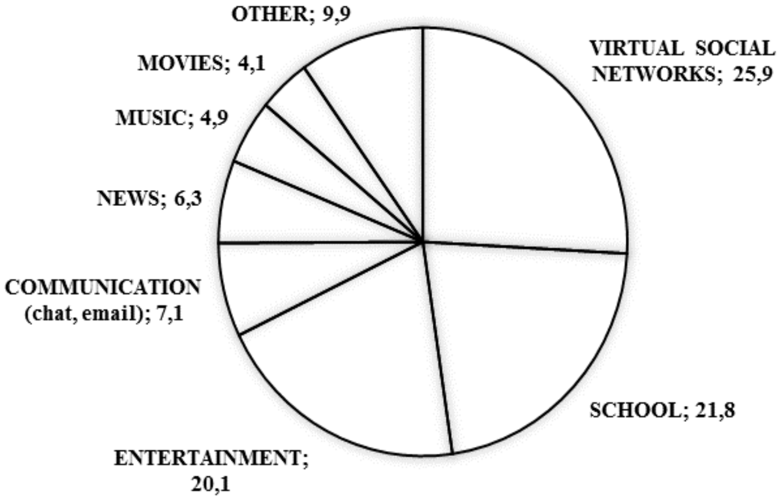


Fig. 1.
The purpose of Internet usage of high school population in the City of Zagreb (in %)
Source: Survey

Figure 1 shows the purpose of Internet usage among high school students in the City of Zagreb. The research showed that the first reason to use the Internet was communication via social media (primarily Facebook), and not via chat or e-mail. The second reason to use the Internet was for school activities (various information, help with writing homework, reports and seminar papers etc.). In addition, the Internet was also used for entertainment for accessing YouTube, games and various other forms of entertainment. Communication via chat and e-mail and other channels (except via social networks) was also popular. Beside access to services that provide various news, the Internet was used to listen and download music and movies. Also there were various other reasons such as browsing transport timetables, on-line betting, writing blogs etc.

As founded, ICT was highly present in everyday lives of students. Therefore, it can be assumed that this technology affects their everyday lives. Almost 90% of students (87.5%) stated that the Internet and mobile phones affected the organization of their everyday life (Table 1). This point was relatively important, as one third of students (34%) stated that ICT often or almost always (i.e. high or very high) affected the organization of everyday life. If students who stated that ICT occasionally (i.e. moderate) affected organization of everyday life are added, then the share of students stating that ICT had influenced their life went up to 71.2%. Only less than one third of students (28.8%) stated that ICT rare (i.e. poor) affected the organization of everyday life.

Table 1
Frequency and strength of the influence of ICT on everyday lives of high school students in the City of Zagreb

Frequency/strength of the influence	Number of students	Share (in %)
Influence	723	87.5
rare / poor	*208*	*28.8*
occasionally / moderate	*269*	*37.2*
often / high	*163*	*22.5*
almost always / very high	*83*	*11.5*
No influence	103	12.5
Total	826	100

Source: Survey

In addition to investigate the presence of ICT in the lives of high school students, the aim was to examine the importance of individual segments of ICT in their everyday lives. In order to examine this issue, the method of self-reported measure was applied. In this process, eight suggested transport (virtual mobility) issues i.e. problems were assessed from the aspect of importance to provide possible impact on students' daily life. Given that students everyday life is different in many aspects, especially in the context of gender and age, it was assumed that there were differences in the importance of the problems. A Likert scale of self-assessment was used in which the students assessed suggested issues. To determine the correlation between age/gender and importance of the issues Pearson correlation coefficient and point-biserial correlation coefficient were used. (Table 2).

Table 2
Correlation of age and gender with the importance of virtual mobility issues

Issue		Age		Gender
Ability to access to Internet whenever you want to	r	-.059	r_{pb}	**.114****
	p	.092	p	.001
Constant and quick access to information via the Internet	r	-.006	r_{pb}	**.128****
	p	.863	p	.000
High speed of "fix" Internet	r	.003	r_{pb}	**.075***
	p	.941	p	.030
High speed of mobile Internet	r	**-.072***	r_{pb}	**.203****
	p	.039	p	.000
Access to virtual social media (e.g. Facebook, Twitter...)	r	**-.118****	r_{pb}	**.230****
	p	.001	p	.000
Feeling safe when using the Internet	r	-.056	r_{pb}	**.256****
	p	.105	p	.000
The possibility of permanent availability via mobile phones and the Internet	r	-.052	r_{pb}	**.218****
	p	.135	p	.000
Covering Internet and mobile phone costs	r	-.011	r_{pb}	**.145****
	p	.763	p	.000

r = Pearson's correlation coefficient; r_{pb} = point-biserial correlation coefficient; p = statistical significance
* $p<0.05$; ** $p<0.01$
Source: Survey

Based on the data shown, it could be assumed that the association between gender and issues was stronger than the association between age and issues. A statistically significant correlation between age and transport issues appeared only in two cases. The obtained results clearly indicate a statistically significant correlation, though low, between gender and issues. This correlation was significant for all issues. It is necessary to note that in all cases, girls gave higher grades to issues than boys did, which might indicate that girls find the proposed issues more important in their daily lives than boys do.

In order to detaily examine the differences between girls and boys within the frame of certain issues, the statistical significance of differences between male and female subjects for a series of test variables was tested using a t-test (Table 3). Though these were not exceptionally large differences in the grade assigned, the t-test indicated that there was a statistically significant difference in the responses between girls and boys. The obtained results were in line with the correlation results. The results of the t-test suggested that girls gave higher grades for transport issues from the aspect of importance in their daily lives. Although the differences between girls and boys were not so pronounced, it can be noted that girls gave higher importance to the access to virtual social networks, to the importance of security when using the Internet, as well as to the importance of high-speed mobile Internet and the possibilities for permanent availability. Such results could indicate a higher importance of virtual mobility in the daily life for girls than for boys.

Table 3
Mean values for the results of assessing the influence of issues on the daily life of high school students and the values of t-test

Issue	M_M	M_F	t	p
Ability to access to Internet whenever you want to	3.77	4.08	**-3.744***	.000
Constant and quick access to information via the Internet	3.79	4.11	**-3.962***	.000
High speed of ''fix'' Internet	3.83	4.04	**-2.524***	.012
High speed of mobile Internet	3.56	4.09	**-6.302***	.000
Access to virtual social media (e.g. Facebook, Twitter...)	3.26	3.88	**-7.034***	.000
Safety when using the Internet	3.20	3.91	**-7.887***	.000
The possibility of permanent availability via mobile phones and the Internet	3.59	4.14	**-6.659***	.000
Covering Internet and mobile phone costs	3.15	3.54	**-4.490***	.000

M_M = mean of the results for males; M_F = mean of the results for females; t = value of t-test; p = statistical significance
* $p<0.05$
Source: Survey

The impact of ICT on the organization of daily life will be mainly manifested in its two segments. In accordance with the results of the reasons for using the Internet, the impact was most prominent in communication with friends and within the school activities.

Friendship is very important component of young peoples' life. They establish and maintain as many friendships as possible, and these friendships tend to have longer duration compared to those from childhood. High school students have more friends than adults and communicate with them more than adults (Boneva et al., 2006). This communication is carried out in the context of physical meetings, but also through virtual mobility, of which the most important channels of communication are through mobile phones and virtual social networks accessed via computers, but also mobile phones. Still, some studies have shown that the need for intensive communication decreases from adolescence to adulthood with regard to increasing stability of personal identity. For example, older teens have less friends than younger teens (Boneva et al., 2006). This is also shown by the data, which showed that the number of good friends of high school students from Zagreb slowly decreased with age. This proves the correlation coefficient ($r = -.074$, $p<0.05$), indicating a slight, but statistically significant correlation.

In the context of social interactions, a great majority of high school students was using ICT for the formation of new relationships, as well as to maintain existing friendships. Young people are keeping their social life during adolescence through both, physical and virtual meetings (Mesch, 2009). This was certainly confirmed by the survey of high school students in Zagreb. It should be noted that ICT had more significance in the frequency of communication with good friends as more than half of the surveyed students (58.7%) communicated in this way very often with good friends (i.e. every day). Unlike virtual meetings, 48.7% of high school students communicate very often (i.e. every day) with their good friends through physical companionship. It can be seen that good friends of high school students are people who do not necessarily go with them in the same class or even in the same school since students communicate with them often (i.e. a few times a week) through physical meetings (41.9%) indicating a temporary meetings during the week or evening outings on weekends. This was also evidenced by the frequent communications (i.e. a few times a week) with good friends via the Internet and mobile phones which accounted for 31.4%, being ten percent less than the physical companionship. Finally, it can be concluded that friendship had a very great importance in the lives of high school students as they communicated with their close friends very often, while emphasis is put on the communication via the Internet and mobile technology rather than to the physical companionship. This allowed communication with friends with whom it was not possible to physically meet on daily basis, partly overcoming the physical distance between them.

Table 4
Frequency of the communication with good friends

Frequency	Physical companionship		ICT	
	Number	Share (in %)	Number	Share (in %)
Never	4	0.4	6	0.7
Rare (several times a year)	13	1.6	17	2.1
Occasionally (several times a month)	61	7.4	59	7.1
Often (several times a week)	346	41.9	259	31.4
Always (every day)	402	48.7	485	58.7
Total	826	100	826	100

Source: Survey

When analyzing the importance of ICT in establishing new and maintaining existing social interactions, it can be asked if the usage of ICT affected the number of friends. In fact, some research had shown that teens who spend lots of time on the Internet, had less social contact with family and friends in comparison to those who use it less (e.g. Kraut et al., 1998). In contrast, other studies had found that youth increase their social interaction just by using the Internet (e.g. the Pew Internet and American Life Project, 2002). Analysis of this issue in the City of Zagreb showed that the frequency of using ICT had no connections with a number of good friends. Correlation analysis showed statistically insignificant correlation between the time spent on the Internet and the number of close friends ($r = .041$; $p>0.05$), and between the time spent on virtual social networks and the number of good friends ($r = .051$, $p>0.05$). Students stated that the Internet and mobile phones helped in communicating with friends, with no effect on the number of friends.

- *Number of friends does not depend on the mobile phone and the Internet. We would hang out with them one way or another.*
  (female student, 17 years, Trešnjevka)
- *I think I would have the same number of friends. They are friends from my childhood and from elementary school.*
  (male student, 17 years, Centar)
- *I think it does not affect the number of friends. I see my friends every day and because of mobile phones we talk even more. It is better for us because we could see and hear each other.*
  (female student, 16 years, Botinec)
- *I think I even meet my friends more often because of mobile phones. We make a deal via mobile phone and then meet.*
  (male student, 18 years, Malešnica)

However, there are also students who feel that ICT influence the friendship in the context of reduced mutual physical meetings.

- *I think I see some of my friends less because they are affected by this.*
  (male student, 16 years, Jarun)

Despite the fact that students consider ICT useful for socializing with friends, some students think that quality of physical meetings declined because of ICT.

- *Typing the mobile phone when you're having coffee… What's the point at all to see anyone if they are all using the mobile phone.*
  (male student, 17 years, Centre)
- *I am totally irritated when I am with friends and when people do not communicate but are constantly on the phone. I find that stupid. If you are with a person then rather talk to him/her or him and socialize, and not to check Instagram, Facebook etc. All that can wait.*
  (female student, 16 years, Botinec)
- *People lose confidence. It is easier to communicate via mobile phones and other applications, and when we meet face to face there is eerie silence.*
  (female student, 14 years, Trešnjevka)

As the virtual social networks are extremely important element in communicating with friends, and considering that the usage of virtual social networks is the most important reason for using the Internet, usage of virtual social networks was additionally examined. Thus, 95.4% of students (788 of them) used virtual social networks to some extent, while only 4.6% (38 of students) did not use them. The significance of virtual social networks in the daily lives of high school students was extremely high as shown by the average time of their use that was 2.6 hours per day, being 60% of the total time spent on the Internet. Thereat, girls used virtual social networks more than boys, confirmed by the correlation coefficient ($r = .241$, $p<0.01$), indicating a statistically significant correlation. This result was confirmed by the t-test ($t = -6.965$, $p<0.01$). It could be assumed that social interaction was more important in life for girls than for boys. This was also indicated by the correlation between frequency of communication with good friends via the Internet and mobile phones and gender in favor of girls ($r = .196$, $p<0.01$). This was a slight correlation, but statistically significant and obviously systemically present, which was also confirmed by the t-test ($t = -5.741$; $p<0.01$). Greater importance of social interaction for girls was indicated by the correlation between frequency of communication with good friends via physical meetings and gender, being in favor of girls ($r = .142$, $p<0.01$); here a slight, but statistically significant correlation was present ($t = -4.105$; $p<0.01$).

Impact of ICT on school activities was certainly expected, as this was an activity that all students were regularly engaged every day. For this purpose, students' attitudes related to the impact of ICT on school activities were examined (Table 5). Interestingly, more than two-thirds of students (76.2%) stated that ICT affected their school activities. This indicated the great importance of ICT in their everyday life. Thereby, ICT had quite a significant impact on school activities of students. Namely, 43.6% of students stated that ICT often or almost always (i.e. high or very high) affected their school activities. In addition to students who stated that ICT occasionally (i.e. moderate) influences (37.8% of students), then the share was rather high 81.4%. Only less than a fifth of students (18.6%) stated that ICT rare (i.e. poor) affected the school activities.

Table 5

Frequency and strength of the influence of ICT on the school activities of high school students in the City of Zagreb

Frequency/strength of the influence	Number of students	Share (in %)
Influence	629	76.2
rare / poor	*117*	*18.6*
occasionally / moderate	*238*	*37.8*
often / high	*200*	*31.8*
almost always / very high	*74*	*11.8*
No influence	197	23.8
Total	826	100

Source: Survey

Table 6

Ways in which ICT impacts the school activities of students

Way of influence	Number of students	Share (in %)
Help in performing school activities	287	45.6
Negative impact on performance of school activities	342	54.4
Total	629	100

Source: Survey

Impact of ICT on school activities of students was reflected through two segments (Table 6). Students stated that ICT helped in performing their school activities (45.6%). This assistance was evident in several aspects. Students stated that ICT allowed access to additional information for the courses. In addition, ICT allowed communication with each other (via e.g. social networks, emails, SMSs etc.) based on which students shared information about curricula and different information related to school activities. It is interesting to point out how students used ICT for illegal acts related to school activities. It was about a use of ICT in writing exams within the illicit use, as well as the taking photos of exams and sharing them later.

- *I think it has more positive than negative effect. We can check an exam or reading, we do not have to go to friend to look at it. We send in via the Internet.*
  (male student, 16 years, Medveščak)
- *On Facebook we have a group, called the 2d, where you put some questions, sub-questions, "... let me get this ...", "... can you help me ...", I think that it is much more useful than look it up in the book and wasting time.*
  (female student, 16 years, Pantovčak)
- *It is easier to find help. When we went to the elementary school we all lived close to each other, now that we're in the secondary a lot of people do not live close to each other and it is easier for lot of us, we do not have to travel to each other.*
  (female student, 16 years, Botinec)
- *It is easier for us to reach some data, for example for Croatian language, reading, mathematics where we have a page with solutions so we can check our homework.*
  (female student, 18 years, Špansko)
- *ICT helps. In order not to learn everything from books, we take photos of some scripts. It serves as a source of knowledge, all can be found on the Internet.*
  (male student, 18 years, Centar)
- *During the Latin language, many times it helped me to get the translation of the text, I just take a photo and choose to "translate" the Croatian and it translate it more or less accurately.*
  (male student, 15 years old, Kustošija)

Apart from help in performing the school obligations, students stated that ICT had negative impact on their school activities. It is interesting that the proportion of students with such an attitude was more than half of respondents (54.4%). The students thought that Internet and mobile phones distracted from the learning, so it sometimes even threated in certain subjects.

- *It affects by the time spend on the Internet. It can be quite addictive.*
  [Do you think you learn less?]
  Yes. I'm aware of that, but I cannot help myself.
  (male student, 16 years, Centar)
- *It influences negatively, when I have to learn, I'm on the phone for an hour, sitting beside a book and then the time pass in doing nothing, I don't learn and get negative mark.*
  [Are you aware of the problem?]
  I am aware of the problem, but cannot give up '.
  [Why?]
  I do not know. I have no motivation regardless of grades. When I leave it, every five minutes I go and check it for if there's something new, and always like that.
  (male student, 16 years, Vrapče)
- *I understand that this is not good and that I am addicted to these social networks but I don't do anything to reduce it. I am aware that my school activities suffer because of it.*
  (female student, 18 years, Lučko)
- *It affects when we learn. And if there is nothing on Facebook I still have to go on Facebook because I do not want to learn, so I rather go to Facebook.*
  (female student, 15 years, Savica)
- *ICT threatens us. If we didn't have a mobile phone and the Internet and Facebook we could learn more.*
  (female student, 18 years, Jarun)

Beside the students' opinion that ICT affects their school activities both, positively and negatively, their school success to some extent depends on ICT technology. Namely, after analyzing the correlation between school success and ICT a slight correlation was observed between the time spent on the Internet and school success. This was a statistically significant correlation ($r = -.099$, $p<0.01$), indicating a poorer school success of students with the increase in time spent on the Internet. Also, a slight, though statistically significant correlation occurred between the variables of school success and time spent on social networks ($r = -.084$, $p<0.05$).

In order to confirm obtained results, the time spent on the Internet and social media were placed in tabular correlation with school success (Table 7). Thereby, time spent on the Internet and social media were divided into classes. This analysis showed that decrease in school success was related to the increase in time spent on the Internet and social media. However, the value of school success was not reduced substantially, therefore the difference in the school success of high school students who spent more and less time on the Internet and social media was relatively slight.

Table 7
Relation between time spent on the Internet, social media and school success

Time (in hours)	School success (in the case of the Internet)	School success (in the case of the social media)
0 – 2.9	3.96	3.95
3 – 5.9	3.95	3.89
6 – 8.9	3.80	3.88
> 9	3.76	3.81

Source: Survey

It can be concluded that in the domain of school success the time spent on the Internet and on social media had slight impact. Certainly, it should be investigated in which segment of cognitive skills ICT eventually had more significant impact. Given the scope and complexity of such research, it is certainly a separate research topic.

In the context of the spatial segment of research, the correlation between the location of the student's residence and the use of ICT were examined. This study was conducted at the schools in the city center. This means that students who spend more time on the traveling to school live closer to the city periphery. But statistically significant correlation between travel time to school and time spent on the Internet and social media was not found ($r = .005$; $p>0.05$; $r = .043$; $p>0.05$). These results were also confirmed by students.

- *It doesn't matter where someone lives. While I am in the bus to school or from school I use the Internet or I chat with my friends who are already at home. And they are also at home using the Internet. I think we spend the time on the Internet equally.*
  (female student, 16 years, Botinec)
- *I think that we use the Internet equally. We use the Internet, social networks, mobile phones, there is no correlation with living location.*
  (male student, 18 years, Centar)
- *We use the Internet and social media when we need and when we want, no matter where we live.*
  (male student, 16 years, Medveščak)

4. Conclusion

The results showed that ICT usage was very much present in the everyday lives of students. The possession and use of ICT increases the mobility of young people. They use ICT mainly to communicate with friends, especially via virtual social media, and in the context of school activities (getting information, assistance in writing homework, reports and seminar papers). The results showed that ICT helped in communicating with friends, but with no effect to the number of friends. Analysis showed the decrease in school success related to the increase in time spent on the Internet and social media, though the correlation between ICT usage and school success is relatively slight. It should be noted that students were deeply aware of the disadvantages of Internet and mobile phones usage in the context of neglecting their duties. Obtained results could indicate a higher importance of virtual mobility in the daily life for girls than for boys.

High school population are the group of society that is most often engaged in virtual mobility. This work showed that ICT has an impact on some segments of their lives. Since there are not so many papers that study the impact of ICT on lives of high school students, certainly it would be good to broaden researches on various segments of their lives.

Acknowledgements

This research is part of author's doctoral dissertation "Impact of transport disadvantage on everyday life of high school population of City of Zagreb" defended at the University of Zagreb, Faculty of Science, Croatia.

References

Abeele, M.V.; Antheunis, M.L.; Schouten, A.P. 2014. Me, myself and my mobile: A segmentation of youths based on their attitudes towards the mobile phone as a status instrument, *Telematics and Informatics*, 31(2): 194-208.

Adegoke, S.P. 2013. Effect of Internet Browsing on Students' Academic Achievement at the Senior Secondary School Level, *International Journal of Evaluation and Research in Education*, 2(3): 123-128.

Alvarez, M.; Torres, A.; Rodríguez, E.; Padilla, S.; Rodrigo, M.J. 2013. Attitudes and parenting dimensions in parents' regulation of Internet use by primary and secondary school children, *Computers & Education*, 67: 69–78.

Austin, W.; Totaro, M.W. 2011. High School Students' Academic Performance and Internet Usage, *Journal of Economics and Economic Education Research*, 12(1): 30-45.

Badasyan, N.; Silva, S. 2012. The Impact of Internet Access at Home and/or School on Students' Academic Performance in Brazil. Available from Internet: < http://ssrn.com/abstract=2133609>.

Barbieri, P.N. et al. 2016. Let young people join the legislative process. A Twitter based experiment on internships, *Computers in Human Behavior*, 60: 468-482.

Billieux, J. 2012. Problematic use of the mobile phone: a literature review and a pathways model, *Current Psychiatry Reviews*, 8(4): 1-9.

Boneva, B.S.; Quinn, A.; Kraut, E.R.; Kiesler, S.; Shklovski, I. 2006. Teenage Communication in the Instant Messaging Era, In *Computers, Phones, and the Internet: Domesticating Information Technology* (eds. Kraut, R.; Brynin M.; Kiesler, S.). Oxford University Press. United Kingdom. 201-218.

Council for children of the Government of the Republic of Croatia and National institute for protection of family, maternity and youth. 2003. Etički kodeks istraživanja s djecom (Code of Ethics of Research with Children; In Croatian). Available from Internet: <http://www.dijete.hr/en/documents/doc_view/232-etiki-kodeks-istraivanja-sdjecom.raw?tmpl=component>.

Daraha, K. 2013. The effect of the internet use on high school students: A case study of Pattani province of Thailand, *Procedia - Social and Behavioral Sciences*, 91: 241-256.

Gašparović, S. 2014. Impact of transport disadvantage on education of high school population of the City of Zagreb. In *Proceedings of the Second International Conference on Traffic and Transport Engineering ICTTE Belgrade 2014*, 789-800.

Gašparović, S. 2016. Theoretical Postulates of Transport Disadvantage, *Hrvatski geografski glasnik*, 78(1): 73-95.

Jackson, L.A.; Vo Eye, A.; Biocca, F. 2006. Children's Home Internet Use. Antecedents and Psychological, Social, and Academic Consequences. In *Computers, Phones, and the Internet: Domesticating Information Technology* (eds. Kraut, R.; Brynin M.; Kiesler, S.). Oxford University Press. United Kingdom. 145-167.

Kenyon, S.; Lyons, G.; Rafferty, J. 2002. Transport and social exclusion: investigating the possibility of promoting inclusion through virtual mobility, *Journal of Transport Geography*, 10(3): 207-219.

Kraut, R.; Patterson, M.; Lundmark, V.; Kiesler, S.; Mukopadhyay, T.; Scherlis, W. 1998. Internet paradox: A social technology that reduces social involvement and psychological well-being?. *American Psychologist*, 53(9): 1017-1031.

Larsen, J.; Urry, J.; Axhausen, K. 2006. *Mobilities, Networks, Geographies*, Ashgate, United Kingdom.

Lee, S.J.; Chae, Y.G. 2007. Children's Internet use in a family context: Influence on family relationships and Parental Mediation., *Cyber Psychology and Behavior*, 10(5): 640-644.

Lee, Y.K.; Chang, C.T.; Lin, Y.; Cheng, Z.H. 2014. The dark side of smartphone usage: psychological traits, compulsive behavior and technostress, *Computers in Human Behavior*, 31: 373-383.

Livingstone, S. 2006. Children's Privacy Online: Experimenting with Boundaries Within and Beyond the Family. In *Computers, Phones, and the Internet: Domesticating Information Technology* (eds. Kraut, R.; Brynin M.; Kiesler, S.). Oxford University Press. United Kingdom. 128-144.

Livingstone, S.; Haddon, L.; Görzig, A.; Ólafsson, K. 2011. Risks and safety on the Internet: The perspective of European children. Full Findings. Available from Internet: <http://www.lse.ac.uk>.

Mandarić, V. 2012. Novi mediji i rizično ponašanje djece i mladih (New Media and Risky Behaviour of Children and the Young; In Croatian), *Bogoslovska smotra*, 82(1): 131-149.

Mesch, G.S. 2009. The Internet and Youth Culture, *The Hedgehog Review*, 11(1): 50-60.

Montgomery, K.C. 2015. Youth and surveillance in the Facebook era: Policy interventions and social implications, *Telecommunications Policy*, 39(9): 771-786.

Nikodem, K.; Kudek Mirošević, J.; Bunjevac Nikodem, S. 2014. Internet i svakodnevne obaveze djece. Analiza povezanosti korištenja interneta i svakodnevnih obaveza zagrebačkih osnovnoškolaca (The Internet and Children's Responsibilities. An Analysis of the Relationship Between the Use of Internet and Everyday Responsibilities of Primary School Children in Zagreb; In Croatian), *Socijalna ekologija*, 23(3): 211-236.

Omar, S.Z.; Daud, A.; Hassan, S.Md.; Bolong, J.; Teimmouri, M. 2014. Children Internet Usage: Opportunities for Self Development, *Procedia - Social and Behavioral Sciences*, 155(6): 75-80.

Özgür, H. 2016. The relationship between Internet parenting styles and Internet usage of children and adolescents, *Computers in Human Behavior*, 60: 411-424.

Paus-Hasebrink, I.; Wijnen, C.W.; Jadin, T. 2010. Opportunities of Web 2.0: Potentials of learning, *International Journal of Media and Cultural Politics*, 6(1): 9-24.

Pew Internet and American Life Project, 2002. The digital disconnect: The widening gap between Internet savvy students and their schools. Available from Internet: <http:// www.pewinternet.org>.

Puharić, Z.; Stašević, I.; Ropac, D.; Npetričević, N.; Jurišić, I. 2015. Istraživanje čimbenika nastanka ovisnosti o internetu (A study investigating the factors of Internet addiction; In Croatian), *Acta Medica Croatica*, 68(4-5): 361-372.

Ružić, N. 2011. Internet i videoigre: uzročnici povećane agresivnosti među mladima (The Internet and Video Games: Causes of Increased Aggressiveness Among Young People; In Croatian), *Medijske strukture*, 2(3-4): 16-27.

Seo, D.G.; Park, Y.; Kim, M.K.; Park, J. 2016. Mobile phone dependency and its impacts on adolescents' social and academic behaviors, *Computers in Human Behavior*, 63: 282-292.

Siomos, K.; Paradeisioti, A.; Hadjimarcou, M.; Mappouras, D.G.; Kalakouta, O.; Avagianou, P.; Floros, G. 2013. The impact of Internet and PC addiction in school performance of Cypriot adolescents, *Studies in Health Technology and Informatics*, 191: 90-94.

Soohyun, K. 2011. *Effects of Internet Use on Academic Achievement and Behavioral Adjustment among South Korean Adolescents: Mediating and Moderating Roles of Parental Factors*, Child and Family Studies – Dissertations, Syracuse University, U.S.A.

Woods, H.C.; Scott, H. 2016. Sleepyteens: Social media use in adolescence is associated with poor sleep quality, anxiety, depression and low self-esteem, *Journal of Adolescence*, 51: 41-49.

Zhu, J.; Zhang, W.; Yu, C.; Bao, Z. 2015. Early adolescent Internet game addiction in context: How parents, school, and peers impact youth, *Computers in Human Behavior*, 50: 159-168.

THE IMPACT OF PUBLIC DATA AVAILABLE FROM SOCIAL NETWORKS ON AIR TRAFFIC SECURITY AND SAFETY

Dušan Crnogorac[1], Svetlana Čičević[2]
[1,2] University of Belgrade, Faculty for Transport and Traffic Engineering, Belgrade, Serbia

Abstract: Recent events regarding air traffic and transport (such as terrorist attacks) indicated the necessity to explore crew publicly available data from social networks. The main purpose of this research is to increase awareness of air traffic and security companies, to the risks of publicly available data and emphasize the threat to public safety. The sample included identification of pilots and co-pilots in selected airlines. Starting from public profile available on a business network, the search was performed trough all other social network sites where the employee had or could have personal data. The findings from this research suggest that air traffic and transport companies involved have to increase alertness level as well as to educate their employees on the risks of disclosing private information. This knowledge could make a significant contribution to air transport and traffic security and safety.

Keywords: air traffic, social network, public data, pilot, aircraft, airline, terrorist, aircraft security.

1. Introduction

Air traffic and transport has always been a convenient target for terrorist groups. While airports, airlines, and Air traffic control information technology systems have been identified as critical transportation infrastructure, currently, a growing threat to the safety and security of the global aviation system, as one of the most complex and integrated systems of information and communications technology, lies in cyberspace. The high degree of interconnectivity and access by employees and airspace users, to enterprise networks, is expected to achieve efficiencies, improve system performance and productivity, and increase safety through automation. While the benefits have been enormous, at the same time, creates significant inherent security vulnerabilities, making it a potential target for a large-scale cyber attacks.

Cybersecurity relies on technology, operations, and people. Notwithstanding an essential element of cybersecurity has always been the human portion of the triangle (von Solms & Warren, 2011), an acute shortage of comprehensive scientific literature upon it is evident. Nevertheless, several references could be extracted recognizing the potential issues related to the topic of awareness of cybersecurity threats posed by employees' inappropriate usage of Social Network Sites (SNS) for aviation system safety.

Airplanes have limited resources to conduct a safe landing. Every flight is time limited and it involves many people. Last airport attacks increased the level of airport safety and security (AIAA Decision Paper, 2013, Jeyakodi, 2015).

Despite the fact that Aviation is a unique critical national infrastructure that requires the application of higher standards of security to fortify their systems from cyber-attacks, till now, there is no single comprehensive approach to cyber security in civil aviation. Cyber standards, security and enforcement are still in their nascent stages.

The first step resolving such situation would be to see the complete picture by assessment of the spectrum of these new and emerging threats, in order to properly understand, identify and accept their existence, and coherently deal with the risks to people, institutions, and the economy (Mueller and Stewart, 2011). Moreover, a cyber security culture must be established.

Thus, the main purpose of this study was to show how easy is to gather the extensive amount of Personally Identifiable Information about pilots and co-pilots, working for two airlines, that are freely available through various social network sites and generally accessible, which makes them easy to locate either on-line or off-line. Further, the objective was to provide an overview of the measures and strategies to mitigate cyber risks associated with the critical personal information available.

1.1. Social network sites and aviation cyber – security

Social media (SM) has permeated every aspect of society. Social networks are dedicated websites or other application that connect people and enables them to communicate with each other by posting messages, comments, images etc. Social networks connect people at low cost and this is the main reason for such a wide usage. There are more than two hundred known social networks. At their early beginnings, SNS started to make contacts with people and build a network of healthy relationship in the society.

But due to the overwhelming amount of information generated, exchanged, and redistributed by users, now it seems they became an easy way for confidential personal information to be accidentally or deliberately exposed. Representing a new range of online uses, they pose a series of challenges to the security community, offering cybercriminals a great advantage to target victims. Thus, the adoption of new tools and techniques to search, analyze and secure online data is demanded.

Social networks (SN) have changed the ways in which users interact, share information (personal data, opinions, news), and conduct business on-line, transforming the familiar communication-focused Internet into a new social platform. Because SNS enable users to articulate and make visible their social networks, the public display of connections is a

[1]Corresponding author: crni@sf.bg.ac.rs

crucial component of these services. The ability to share different social information with different groups is a key characteristic of social identities.

Every day millions of people around the world post messages via social media in order to share thoughts, ideas, strategies, resources. These technologies generate an enormous amount of data, from which we can obtain valuable information for different purposes, from the emergency management to the intelligence (Cresci et al, 2016).

People of all ages, around the world, knowingly and willingly use Facebook, Twitter, LinkedIn, Match.com, Friendster, or MySpace, as one of still usable network for gathering information, as well as hundred other sites to communicate, find friends, dates, and jobs – and in doing so, they wittingly reveal highly personal information to friends, as well as strangers.

A cyber-terrorist may hack into critical infrastructure in an attempt to cause grave harm such as loss of life or significant economic damage. Such attacks are aimed at wreaking havoc on information technology systems that are an integral part of public safety, traffic control, medical and emergency services, and public works (Maras, 2012).

In the decade since its inception, social media, such as LinkedIn, Twitter, Facebook, YouTube, etc., has become a powerful tool for communication. The majority of online users are currently attached to more than one social network. Individuals usually belong to several social groups simultaneously and share different personal facets with the members of each group. From the personal spaces of Facebook, MySpace, Orkut, and Windows Live to more interactive platforms, such as wikis, blogs, Twitter, and online worlds (e.g., Second Life, World of War-craft), hundreds of millions of users are connecting with each other and building online communities. Furthermore, a more cyber-oriented workforce, accessing SNS from different locations by Social Networking applications on smartphones and other numerous mobile devices, could skew the information path patterns in unexpected ways with undesirable consequences.

Social networks serve two main purposes: to connect with friends, share personal information and meet new people; and to connect professionals, share knowledge, experiences and plan future career steps (Trusov, Bucklin and Pauwels, 2009).

While Facebook and Twitter are mainly focused on the first purpose of SN, with users sharing pictures and personal information (Papacharissi, 2010; Dutta and Fraser, 2009), LinkedIn fosters the second one. Here, individuals long to market their skills, competences and work experience and to connect with professionals in their or similar fields of expertise (Dutta and Fraser, 2009). Individuals upload job qualifications and application information on their LinkedIn profile.

SNS users drive both demand and supply – content creation is as easy as content access; information analysis is as easy as information dissemination. Thus, several drawbacks are associated with the SNS usage.

Traditional offline criminals also use social networks to plan criminal activities or are targeting their activities to online victims, so offline criminal activity is migrating to cyberspace. Cyber-criminals have adapted their strategies and tools to target social-network users and have improved attack technologies.

Unfortunately, a high percentage of social media users allow their information to remain public. Gross and Acquisti (2005) after analyzing 4000 Facebook profiles of Carnegie Mellon University students, found threats emerging from personal information posted in social networking site. Only 1.2 percent of users changed their default privacy preferences. Hence fully identifiable information like (first name, last name, personal image, hometown, date of birth, ZIP code) were easily available to anyone registered on Facebook. These information could be used, for example, to estimate a person's social security number or finding sensitive medical information (Gross, & Acquisti, 2005).

Using the information available on Facebook profile one can easily determine the likely physical location of a person. Similarly, the research done by Bit Defender reveals that 75 percent of individuals use the same password for social networking sites and email (Study reveals 75, 2010).

Today, many Open source intelligence (OSINT) tools for gathering and analyzing data for intelligence purposes could be employed, as well as, a lot of products were developed for professional data mining technology to dig up the potential connection between different groups and individuals on social networks, providing Personal Profile, Personal Relationship Analysis, Personal Mention Analysis, Personal Messages List, Personal Content Analysis, etc. However, countries of poor economic status cannot afford such applications (tools). But despite this fact, as users unintended and uncareful behavior on SNS still remain the weakest element in the chain of events, this study was focused on its security implications and perspectives on potential future development paths, using only data mined freely available on the web.

The motivation for choosing LinkedIn (before their merge with Microsoft) as a starting point in this investigation was the fact that, many employees are still using public facing social networking sites to manage their career. Further, speaking of spear phishing, ‘invitation to connect on LinkedIn’ is consistently listed among the most-used subject lines in phishing scams. In addition to completely fabricated accounts, it’s very common for hackers, scam artists and terrorists to create fake profiles for real life individuals.

With respect to the fact that human factors, alongside with the technical infrastructure, are susceptible to making errors which could compromise aviation safety, pilots and co-pilots were found in the focus of this research, having in mind, that, besides own errors, they can also be exposed as targets for terrorists, who aim to search for, and find them.

Any mistake (accidental or intentional) made by these two bear the potential to be fatal, or even producing the chaos and resulting economic losses, and finally, there also exists an angle of psychological threat, whereby cyber interference may play havoc on the integrity of air transport. Therefore, it is clear, that terrorists analyze publicly available data to gather information on pilots or co-pilots, in order to reach and blackmail them or use other means of force to violate airplane safety. As global political crisis does not know borders or boundaries, samples (companies) originated from different continents.

2. Data available on SNS

The main goal of the study was to collect personal data about pilots and co-pilots, working for two airlines, that are available from business social network "LinkedIn". One European and one airline from the Middle East were selected, for which it is assumed that they, probably, could be in the focus of terrorist groups. The further step was to analyze various kind and amount of sensitive personally identifiable information (PII), freely available on the web, that could be collected and reached without requiring visitors to be registered or logging in.
Information comes from scanning LinkedIn for the key words: "pilot xxx airlines" where xxx represents the name of the company (airline). In order to protect the confidentiality of Airline operators studied, in the further text, they will be designated as "X Airline" and "Y Airline", respectively. The number of employees found is in Table 1.

Table 1
Search Results for the selected airlines (number of employees found)

X Airline	Y Airline
142	1144

From search results for the "X Airline", only 80 people were employed as pilots in selected airline, other 62 from search results were connected to keywords but not relevant for research. Therefore, further analysis was conducted on 80 persons who, actually, are pilots employed by the airline. For the second airline, "Y Airline", 100 persons comprised the representative sample for analysis (Table 2).

Table 2
Publicly available profiles for two samples

	X Airline		Y Airline	
	N°	%	N°	%
Sample size	80		100	
Public profile	42	52,50	50	50,00

2.1. Types of data available on SNS

Persons who wanted to secure their online data have hidden their profile to all visitors except for registered recruit accounts (head hunters). This kind of data was marked as N/A (Table 3).
Still, the following data resulted from the search results could occur – the name of the employee is hidden, but there was a personal photo present and visible to all, or cover photo including a family member (partner or a child). Likewise, if there is a personal photo available, we could determine person's gender. Business data available were person employment history and education.
After gathering this information, advanced search for the same person by its name and surname on dozen most popular social networks was conducted.
Home area data information was collected in order to narrow search results of the extensive amount of data gathered for first and last name combination as key words.
Hobby was indicated if existed or it was mentioned. For comparisons, available additional information on a number of persons and different groups connected to examinees were collected.
For people with profiles on multiple social networks, if the same group was found on different SNS, they were treated as one.
The number of published photographs indicates the total number of all the pictures on one`s profile, regardless what they represent. Photos from travels often include family members so they were interesting from that aspect, and travel tags were interesting for further travel analysis. Family photographs indicate if there were family pictures visible, as well as personal and partners photo. A number of children was relevant to gain full vulnerability of a person. The last information considering possible addresses were relevant only for the X airline (white pages were not available online in case of Y airline).

Table 3
Outcomes of search results (data available)

Data	Possible results
Visible name	Name; N
Sex	M; F; N/A
Age	Age; N/A
Business Data	Employer(s), School(s), N/A
Other Social Network Affiliation	Name of Social Network(s), N, N/A
Home area	Area; N/A
Hobby	Y; N/A
Number of groups following on LinkedIn	Number, N/A
Number of linked persons on LinkedIn	Number
Number of different groups following on other Social Networks	Number; N/A
Number of linked persons on other Social Networks	Number, N/A
Is profile visible on Social Networks	Y; N; N/A
Number of published pictures	Number
Pictures from travels	Y; N; N/A
Travel tags	Y; N; N/A
Family photographs	Y; N; N/A
Personal photo	Y; N; N/A
Partners photo	Y; N; N/A
Number of children	Number; N/A
Number of possible addresses	Number; N/A

3. SNS Security – Data Protection

Websites and applications powered by social networks have many restrictions depending on visitor's status. Individual who wish to review and collect data on social network website (or Android application) has to be registered as a member, make its own profile and then reach available data. For that purpose, one needs nothing more than a valid e-mail address. Free e-mail address is available on numerous web services. All social network members can customize their individual privacy settings (lock visibility to a wide audience), control the kind and amount of information they share (make their own public data selection) and limit access to important information.
The first step of the investigation was to find if the employees of two aviation companies have profiles on a social network "LinkedIn". Search results were available only for a limited time period. After two days period search results (if saved) were available only for visitors who have paid membership.
For all social networks, the unique rule was that all the profile data will be visible only to directly connected the third party. So, one has to send a connection request and get confirmation from the particular user in order to see the full profile information.
Only public data available to all members were selected to collect because that would not compromise the identity of persons who were performed the searching tasks on social networks.
Considering profile data availability, there were no significant differences between selected airlines, in both cases, about 50% of the profiles were available. For further analysis only public profiles were selected.
It has to be emphasized that both of the airlines are multicultural and multinational, so there were no differences (of any type, i.e. religion or else) between samples that would contribute to significant issues regarding analysis or interpretation of the results.

4. Results

Analysis of the structure and components of the two airline employees profiles, show the difference in a number of public profiles available on other social networks, i.e., with no restriction of accessing any kind of contents, with detailed personal information provided and visible on one or more social networks (Figure 1). The staff of X Airline who are LinkedIn members are less cautious, one third of them revealed personal information to the wide public audience, while only 7.69% of Y Airline employees could be identified via online search. Obviously, they are much more concerned with their privacy in comparison to the X Airline employees.

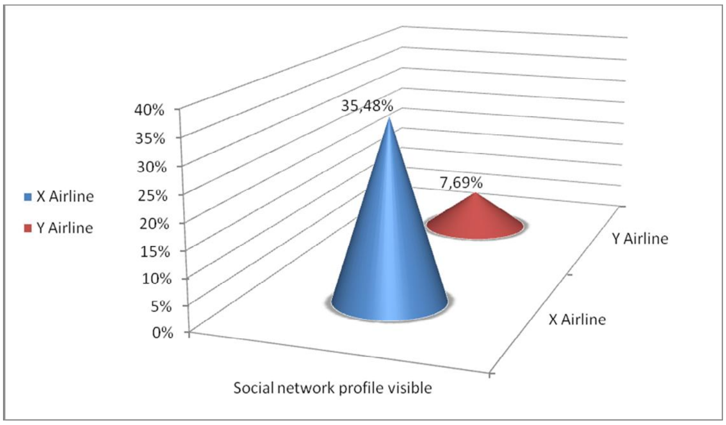


Fig. 1.
Number of Public Profiles Available on Social Networks

The fact that almost all of profiles had visible school and employment history data visible was not surprising. Presence on another SNS was also the subject of analysis. Near 74% of the X Airline employees have profiles on other SNS, besides LinkedIn, as well as 52% of the Y Airline staff. But, the percentage of employees having accounts on more than one SNS is very low, ranging from 4% for Y Airline, to 12 % for X Airline employees (Figure 2). None of the employees has the profile on more than two SNS.

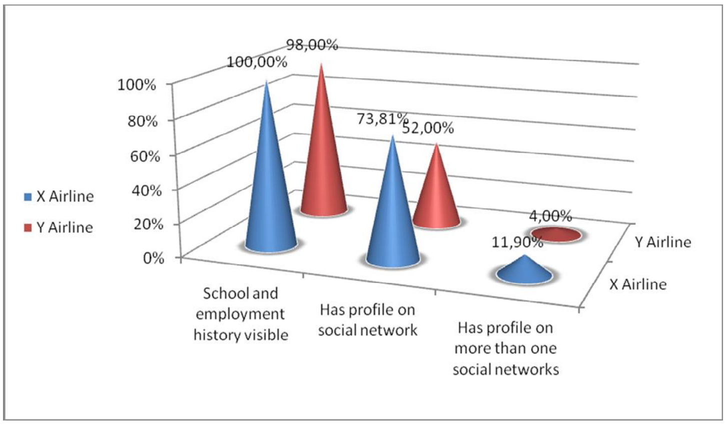


Fig. 2.
Professional history and data about Presence on SNS

Demographic structure of both samples (from the two airlines) were similar. The average age was around 42 years for both samples (42,76 years for the X and 41,54 years for the Y airline). Two airline employees show similarities in some parameters of their online exposure and activities, too. Among them, in a number of groups and followers on LinkedIn, as well as in group membership on other SNS. However, there are some differences in an average number of connections on various SNS and an average number of photos posted on their profiles (Figure 3).

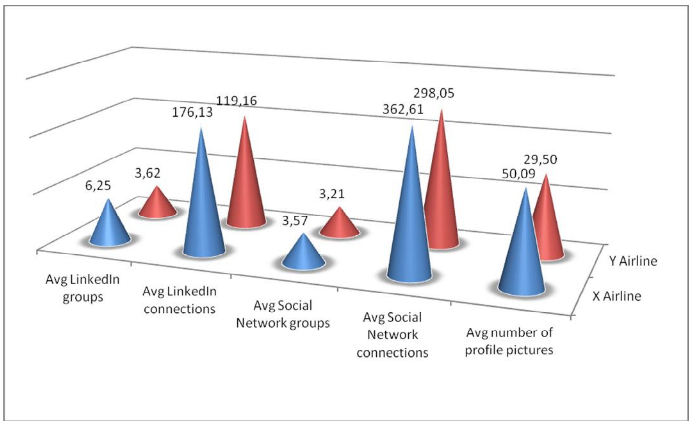


Fig. 3.
Activities on Social Networks

Considering the number of photographs published by members on various social networks, there are differences between the two airlines. Employees from X airline posted more photos, whether personal, their partners (spouse) or photos and data about their children, compared to those from Y airline (Figure 4).

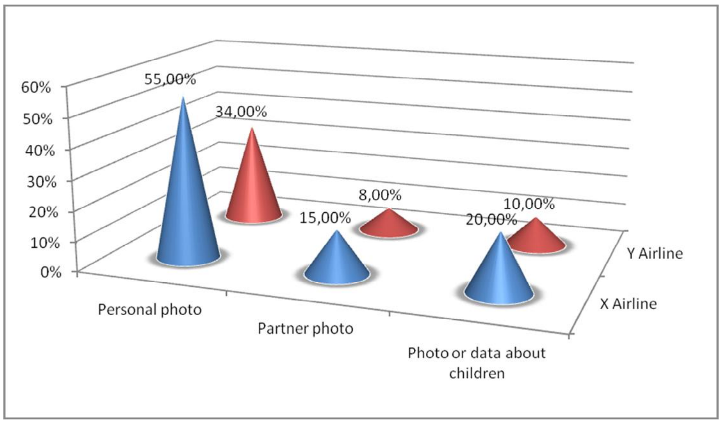


Fig. 4.
Photographs posted on all Social Networks (for two airlines)

On the basis of the results presented, the conclusion could be drawn, that the employees from X airline show higher online exposure in terms of personal information provided and visible on one or more social networks, such as number of profiles on SNS, average number of connections on various SNS and average number of photos posted on their profiles (rather personal or of family members). On the other hand, two airline employees are similar with respect to school and employment history visibility, an average number of groups on other SNS than LinkedIn. Y airline employees are more cautious, much more concerned with their privacy and more selective in the type of information they provide available to a wide audience.

5. Discussion and Conclusion

Personal data security is very important in all aspects of life. Special treatment of personal data is expected for all the employees in air traffic and transport. Groups of employees such as pilots and co-pilots need to be alerted that their personal data should be hidden. With no doubt, users (employees) may compromise personal and systems' security and safety by posting certain types of information on social networking services.
To reduce or eliminate the risk of sensitive or classified information being posted on social networking sites, an organization needs to stipulate in its policies what can and cannot be posted on both internal and external social networks site (Disruptive information technologies, 2010).
As long as individuals, organizations and intelligence analysts are aware of the perils involved in using social networking sites, it will be harder for criminals and terrorists to plan and execute malicious activities and attacks (Social Media: A Valuable Tool With Risks, 2013).
Therefore, pilots and copilots responsible behavior on SN have to become an essential and inevitable part of the cybersecurity of information and communications systems for critical infrastructure technical measures and policies, and in front of all, of an up to date training and educational system in order to establish an well designed ‘human firewall’ of a system.
As could be seen from the results of the study, even simple inspection, via online search, without applying sophisticated OSINT tools and similar products, provide a massive amount of data about airline staff which can be misused making them a potential target for cyber criminals and cyber terrorism.
Thus, an information (cyber) security culture must be established. The information security culture shall consider each human factor carefully to improve user security behavior (Al Hogail, 2015). Al Hogail (2015) discuss the human factor diamond which represents the four domains of human factors that influence information security behavior. The “preparedness” domain is mainly concerned with training and awareness, knowledge acquisition, and change of old practices. The “responsibility” domain is mainly related to employees’ practices and performance such as monitoring and control, reward and deterrence, as well as acceptance of responsibility.
The “management” domain is concerned with security policies, practices, directions, and interaction issues.
Finally, the “society and regulations” domain is mainly related to social and cultural aspects and regulation issues (Al Hogail, 2015).

5. 1. Recommendations

To tackle the problems that may arise from sensitive personally identifiable information being freely available on SNS, it is necessary to identify exploits and vulnerabilities and to make recommending guidelines to various cyber-security threats elimination and prevention.

Measures to protect information and communication technology systems used for civil aviation purposes from interference that may jeopardize the safety of civil aviation must be developed. These measures include, but do not have to be limited to the evaluation, location and prioritizing of cyber-risks, but urge incorporation of unpredictability factors into the system.
The biggest and most important protective measure is user education. Training of personnel at various levels in various capacities to meet the challenges posed by cyber threats is necessary, in order to launch response attacks.
The training should include instruction in using social media in order to feel comfortable using it, as well as how to eliminate personal information from individual social media.
Also, a certification examination for employees which test the employees' cyber-security knowledge.
It is important to point out that there is always the possibility that information posted on the Internet (personal details like date of birth or resume details) can be shared beyond how it was intended.
High priority should be on promoting unceasing awareness, providing leadership through social media education, training, and to diligently manage employees on-line exposure (FBI Law Enforcement Bulletin, 2012).
The Symantec Corporation (Symantec Corporation, 2013) propose seven basic security measures for using social networking sites, regarding sharing passwords to social networking sites; avoiding posting anything that should not be public knowledge like sensitive information such as a phone number, birthdate, or vacation status; ignoring links with "enticing titles" sent by friends; need to verify if posted links (such as on a Facebook wall), are valid; limiting the number of those who can access a profile to family and friends; as well as keeping to be informed of changes to privacy policies of social networking sites (Symantec Norton Report, 2013).
The above-mentioned guidelines are similar to those recommended for Military personnel when posting information using social networking sites (U.S. Army, 2011).
The U.S. Army Social Media Handbook listed "Security Items to Consider":

- "Take a close look at all privacy settings. Set security options to allow visibility to 'friends only'.
- Do not reveal sensitive information about yourself such as schedules and event locations.
- Ask, "What could the wrong person do with this information?" and "Could it compromise the safety of me, my family or my unit?"
- Geotagging is a feature that reveals your location to other people within your network. Consider turning off the GPS function of your smartphone.
- Closely review photos before they go online,
- Make sure they do not give away sensitive information, which could be dangerous if released,
- Make sure to talk to family about operations security and what can and cannot be posted,
- Videos can go viral quickly; make sure they don't give away sensitive information. "

What is well known, but never enough pointed out, is to ensure that password length/complexity/reset/history requirements are defined and configured. Regardless of platform, using secure passwords and encryption on every device that touches the business (phones, tablets, laptops, desktops) is necessary. Moreover, to restrict who can find data via online search and to limit what people can learn about the company through public searching (Ackerman and Schutte, 2015).
Although guidelines listed above referred to the Ministry of Defense and Internet Services Providers, they can be transferred to the Civil Aviation. Hence, the need arises to provide a framework for a risk-based approach to prioritize the protection of high-value information across the system and allocate resources in correlation with the greatest risks, but not of lower importance is to ensure periodic risk assessments. Within this paper only part of the findings is presented, the next steps will include a profound statistical analysis and interpretation of the results.

Acknowledgements

This study was supported by The Ministry of Education, Science and Technological Development of Serbia (project 36022 and 36006).

References

Ackerman, S.; Schutte, K. 2015. *Social Media as a Vector for Cyber Crime*. Clark Schaefer Consulting LLC., Cincinnati, Ohio, U.S.A.
Al Hogail, A. 2015. Cultivating and Assessing an Organizational Information Security Culture; an Empirical Study, *International Journal of Security and Its Applications*, 9(7): 163-178.
Cresci, S.; La Polla, M.N.; Tardelli, S.; Tesconi, M. 2016. *#tweeTag: a web - based annotation tool for Twitter data*, *IIT TR-07/2016. Technical Report*, Istituto di Informatica e Telematica, Pisa, Italy.
Disruptive information technologies 2010. Disruptive information technologies: Cloud computing, social networking, consumerization. Aerospace Industries Association. Available from the Internet: <http://www.aia-aerospace.org/assets/report_ebiz_2010_web.pdf>.
Dutta, S.; Fraser, M. 2009. When job seekers invade Facebook: The increasing popularity of online social networking is changing not only the way people manage their careers but social networking itself, *The McKinsey Quarterly*.

Gross, R.; Alessandro, A. 2005. Information revelation and privacy in online social networks (the facebook case). In Proceedings of the ACM Workshop On Privacy In The Electronic Society (WPES). Available from the Internet: <http://www.heinz.cmu.edu/~acquisti/papers/privacy-facebook-gross-acquisti.pdf>.
Jeyakodi, D. 2015. *Cyber Security in Civil Aviation*. Available from Internet: <http://eala.aero/wp-content/uploads/2016/02/4.-Deepika-Jeyakodi-Cyber-Security-in-Aviation.pdf>.
Maras, M-H. 2012. *Cybercrime Laws: Which Statute for Which Crimes. Computer Forensics: Cybercriminals, Laws, and Evidence*, Jones & Bartlett Learning Sudbury, MA, U.S.A.
Mueller, J.; Stewart, M.G. 2011. *Terror, Security, and Money*, Oxford University Press, Oxford. UK.
Papacharissi, Z. 2009. The virtual geographies of social networks: a comparative analysis of Facebook, LinkedIn, and ASmallWorld, *New Media & Society*, 11(1&2): 199-220.
Social Media: A Valuable Tool With Risks 2013. *Major Cities Chiefs Associates and Federal Bureau of Investigation*, National Executive Institute Associates.
The study reveals 75. 2010. Available from the Internet: <http://www.securityweek.com/study-reveals-75-percent-individuals-use-same-password-social-networking-and-email>.
Symantec Norton Report. 2013. Available from Internet: <www.symantec.com/about/news/resources/press_kits/detail.jsp?pkid=norton-report-2013>.
AIAA Decision Paper 2013. *The Connectivity Challenge: Protecting Critical Assets in a Networked World – A Framework for Aviation Cybersecurity*, The American Institute of Aeronautics and Astronautics (AIAA).
Trusov, M.; Bucklin, R.E.; Pauwels, K. 2009. Effects of word-of-mouth versus traditional marketing: Findings from an internet social networking site, *Journal of Marketing*, 73: 90-102.
U.S. Army 2011. *U.S. Army social media handbook*, U.S. Army Office of the Chief of Public Affairs. Online and Social Media Division, 1500 Pentagon, Washington, D.C., U.S.A.
Waters, G. 2012. *Social Media and Law Enforcement, Potential Risks*, FBI Law Enforcement Bulletin.
Von Solms.; R. Warren, M. 2011. Towards the human information security firewall, *International Journal of Cyber Warfare and Terrorism*, 1(2): 10-17.

SESSION 3: INFORMATION COMMUNICATION TECHNOLOGY AND TRANSPORT

ANALYSIS OF VEHICLE TO INFRASTRUCTURE (V2I) COMMUNICATION EFFICIENCY USING THE ZIGBEE PROTOCOL

Răzvan Andrei Gheorghiu[1], Valentin Iordache[2]
[1,2] Transport Faculty, Electronics Dept. "Politehnica" University of Bucharest – Bucharest, Romania

Abstract: Information is nowadays the key element in every aspect of life. It is easier than ever to acquire and transmit large amount of data that is then used in many systems that control different aspects of the world we live in. This is also true for road traffic information, where modern Traffic Management Systems (TMS) collect information about the vehicles, speed, queues' lengths, emissions etc. - which is afterwards included in complex algorithms that determine the best possible signaling times for the traffic lights in road network junctions. But usually the information is obtained in fixed points of the network, meaning the TMS has detailed knowledge of the actual traffic conditions only in these points and can only assume/estimate what is happening between them. Floating car data represents a method to obtain information from the entire road network, but it implies a more complex communication approach, being able to acquire actuated data along the routes. A dense communication network also implies a considerable amount of energy required for its functioning. Modern communication protocols, such as ZigBee, may be such an alternative, presenting many advantages from these points of view, and may represent a solution for vehicle-to-infrastructure (V2I) communications. In this article the possibility of implementing a communication network based on this protocol has been analyzed, testing the possibility of a faster connection between devices, one of the key elements in implementing a V2I communication network.

Keywords: ZigBee, Wi-Fi, interferences, vehicle-to-infrastructure communication, communication handshake time analysis.

1. Introduction

Communications represents the backbone of any modern transport support system: traffic management, public transport management, passenger information, toll collection, law enforcement and so on.
Implementation of new services or features may be based on existing communications or, if this cannot be done, new communication networks have to be installed. In the latter case a detailed analysis must be carried out for the requirements of information transmission that takes into account the existing communications in order to avoid interference with the consequence of failure to proper submit the information. Analysis of interference with existing networks should be carried out from two perspectives: new implemented network is influenced by existing communications or it can influence the networks already installed.
Communication technologies are mainly improved to allow the transmission of increasingly larger quantities of data. But this is not always necessary, in many cases there is some bandwidth left unused. Neither in terms of energy is this solution proper.
This paper examines the possibility of implementing cheap, energy efficient network that will ensure a minimum (essential) information transfer between vehicles and infrastructure (V2I communications). This network has many practical applications, such as:

- Transmission of certain categories of vehicles' position at certain points in the network: e.g. identify public transport vehicles in the intersections' proximity to ensure their priority,
- Data collection on the route, based on sensors installed on-board of vehicles that download information at every intersection (this information is useful, for example, for traffic management systems),
- Transmission of information related to passengers inside vehicle - useful for evaluating the efficiency of public transport,
- Loading the vehicle information system with updated information related to specific events in the next portion of the route.

The proposed solution is to implement ZigBee communications that meet the requirements defined above, for which we will assess the possibility of implementation, and the effectiveness of communication, given that there are other modes of wireless communication already installed. The paper is structured as follows: Chapter 2 presents a general description of the ZigBee communication protocol, detailing aspects to be taken into account in implementing the network. Chapter 3 presents an analysis of wireless communications that can be present in the vehicular environment, emphasizing their technical characteristics. Chapter 4 offers details regarding possibility of implementing ZigBee mixed with other communications methods, and chapter 5 presents the results of connectivity tests that were carried out in laboratory environment.

2. ZigBee protocol

ZigBee is a wireless communication protocol based on IEEE 802.15.4 specification and designed mainly for high energy efficiency, but having a relatively low data rate compared to other modern communications. It is mainly used for the implementation of the Internet of Things concept, by employing a very good resource management and

[1] Corresponding author: andrei.gheorghiu@upb.ro

implementing a very efficient data transfer that consider only the essential information transmission. It has many advantages, such as reliability and robustness, energy efficiency, scalability, security and universality (ZigBee Alliance, 2016).

The main technical features of ZigBee Technology are (ZigBee Alliance, 2007; Hou et al., 2009):

- Radio Frequency/Bands:
    - 2.4 GHz with 16 channels (in fact 2.4-2.4835 GHz; channels no. 11 to 26) for global use, each of them being 2 MHz wide with 3 MHz inter-channel gap-bands. The center frequency of each channel is calculated as f_{ch} = (2400 + 5*k) MHz, where k = 1, 2, ... 16. The throughput is 250 Kbps,
    - 915 MHz with 10 channels (in fact 902-928 MHz; channels no. 1 to 10) for N. America, Australia and a few additional countries; throughput of 40 Kbps,
    - 868 MHz with 1 channel (in fact 868-870 MHz) for EU countries and Japan.
- Network type: self-organizing, self-healing, ad-hoc dynamic mesh,
- Network size: up to 64,000 nodes managed by a single coordinator,
- Network access: CSMA-CA (Carrier Sense Multiple Access with Collision Avoidance),
- Device types:
    - Coordinator:
        - One ZigBee coordinator per network,
        - Root of the network tree,
        - May bridge to other networks,
        - Stores information about the network (like radio-channel, repository for security keys, etc.).
    - Router:
        - Parse data from other devices,
        - Has the role to extend network range,
    - End-device
- Beacon and non-beacon enabled networks:
    - Beacon enabled network, in which the router sends periodic beacons to other nodes to confirm their presence. The coordinator and the clients wake up from sleep at precise intervals to exchange messages, requiring precise timing. This kind of network has lower duty cycle and extended device battery life,
    - Non-beacon enabled network, in which clients transmit whenever an event occurs and the network coordinator keeps its receiver on all the time, needing more power supply,
- Automatic network establishment by the coordinator
- Modulation: Offset quadrature phase-shift keying (OQPSK) and Direct Sequence Spread Spectrum (DSSS),
- Transmission power: 1 mW (typical),
- Packet length: 352 µs - 4256 µs,
- Addressing modes:
    - 16-bit (short),
    - 64-bit IEEE addressing ,
- Data transfer distance: typical 10 to 75 meters, but can easily reach 100 meters within line of sight and lack of other interferences,
- Battery life: up to 1000 days.

3. Wireless communications overview

In the last years, a lot of communication technologies and many types of indoor or outdoor equipment are using the 2.4GHz band. Some of the possible users and interferers are: 802.11b,g,n networks, Bluetooth Pico-Nets, 802.15.4-based Personal Area Network (PAN), Cordless Phones, Home Monitoring Cameras, Microwave ovens, Wireless headsets, Motorola Canopy systems and WiMAX networks (ZigBee Alliance, 2007). A detailed comparison between these interferers can be observed in Table 1.

Table 1
2.4 GHz band interferers

	No. of channels	Lower frequency	Higher frequency	Spacing	Bandwidth
Wi-Fi	13	2412 MHz	2472 MHz	5 MHz	20 MHz
Bluetooth	79	2402 MHz	2480 MHz	1 MHz	1 MHz
802.15.4	16	2405 MHz	2480 MHz	5 MHz	3 MHz
Cordless phones	-	2400 MHz	2500 MHz	5 MHz, 10 MHz	-
Home monitoring cameras	various specifications, mostly same as Wi-Fi				
Microwave oven	-	2450 MHz	-	-	-
Wireless headsets	various specifications				
Motorola Canopy systems	18	2415 MHz	2457,5 MHz	2,5 MHz+	20 MHz
WiMAX	-	2345 MHz	2360 MHz	-	1,25 - 20 MHz
		2500 MHz	2690 MHz		

When talking about using ZigBee as a solution for V2I communications, some of the presented interferers must be considered. 802.11b,g,n networks are usually stationary, so a particular area in which they are present can be seriously affected by the large volume of data that can be transferred using this technology, this being the case for a road junction. Bluetooth Pico-Nets have a limited range, few network devices and usually small data rates, but they should be considered because some of them may be present in moving vehicles or on the road side (headsets, car keys, etc.). Cordless Phones, Home Monitoring Cameras, Wireless headsets and Microwave ovens are usually used indoors and have less influence on road infrastructure equipment; also, some of them have same specification as Wi-Fi. Motorola Canopy systems are rarely used, but when present they should be considered, and WiMAX networks, as seen from Table 1, are using close frequencies but with small chances of interference. As a conclusion, a more detailed comparison between the most likely to interfere communications in 2.4 GHz band is presented in Table 2.

Table 2
Protocol comparison

Protocol	ZigBee	Wi-Fi	Bluetooth
Modulation technique	Direct Sequence Spread Spectrum (DSSS)	Direct Sequence Spread Spectrum (DSSS), Orthogonal Frequency Division Multiplexing (OFDM)	Frequency Hopping Spread Spectrum (FHSS)
Operating frequency bands	2.4 Ghz, 915 MHz and 868 MHz	2.4 Ghz, 5 Ghz	2.4 Ghz
Maximum network speed	250 kbit/s	several Gbits/s	1 Mbit/s
Network range	Up to 75m	10s of meters up to 100m depending on antennas and line-of-sight	1 or up to 100m, depending on radio class
Typical network join time	30 milliseconds	several seconds	3 seconds
Battery	Not rechargeable (one reason batteries will last for up to 10 years)	Intended for frequent recharging	Intended for frequent recharging

As seen from Table 2, ZigBee communication uses DSSS, and this it helps mitigate coexistence issues with Bluetooth devices (NXP Laboratories, 2013). Also, as mention by Sikora & Groza (2005), tests have shown that the influence of Bluetooth over ZigBee consists in a non-critical increased packet error rate. So, the main issue remains coexistence between ZigBee and Wi-Fi, which will be our approach in this paper.

4. ZigBee – Wi-Fi interferences

In Table 3 is presented a list of the ZigBee channels and Wi-Fi conflicts. It results that channels 1, 6, and 11 of Wi-Fi are the ones that should at first be considered when implementing a ZigBee communication structure in the area. As seen in Figure 1, these channels are more likely to be used because the space between them is big enough so that they don't interfere with each other.

Table 3
ZigBee channels (NXP Laboratories, 2013; Digi Wiki, 2014)

ZigBee channel		Lower Frequency	Centre Frequency	Higher Frequency	Wi-Fi Conflict
dec	hex				
11	0x0B	2.404 GHz	2.405 GHz	2.406 GHz	Overlaps Ch 1
12	0x0C	2.409 GHz	2.410 GHz	2.411 GHz	Overlaps Ch 1
13	0x0D	2.414 GHz	2.415 GHz	2.416 GHz	Overlaps Ch 1
14	0x0E	2.419 GHz	2.420 GHz	2.421 GHz	Overlaps Ch 1
15	0x0F	2.424 GHz	2.425 GHz	2.426 GHz	Overlaps Ch 6
16	0x10	2.429 GHz	2.430 GHz	2.431 GHz	Overlaps Ch 6
17	0x11	2.434 GHz	2.435 GHz	2.436 GHz	Overlaps Ch 6
18	0x12	2.439 GHz	2.440 GHz	2.441 GHz	Overlaps Ch 6
19	0x13	2.444 GHz	2.445 GHz	2.446 GHz	Overlaps Ch 6
20	0x14	2.449 GHz	2.450 GHz	2.451 GHz	Overlaps Ch 11
21	0x15	2.454 GHz	2.455 GHz	2.456 GHz	Overlaps Ch 11
22	0x16	2.459 GHz	2.460 GHz	2.461 GHz	Overlaps Ch 11
23	0x17	2.464 GHz	2.465 GHz	2.466 GHz	Overlaps Ch 11
24	0x18	2.469 GHz	2.470 GHz	2.471 GHz	Overlaps Ch 11
25	0x19	2.474 GHz	2.475 GHz	2.476 GHz	No Conflict
26	0x1A	2.479 GHz	2.480 GHz	2.481 GHz	No Conflict

These conflicts are also represented in Figure 1.

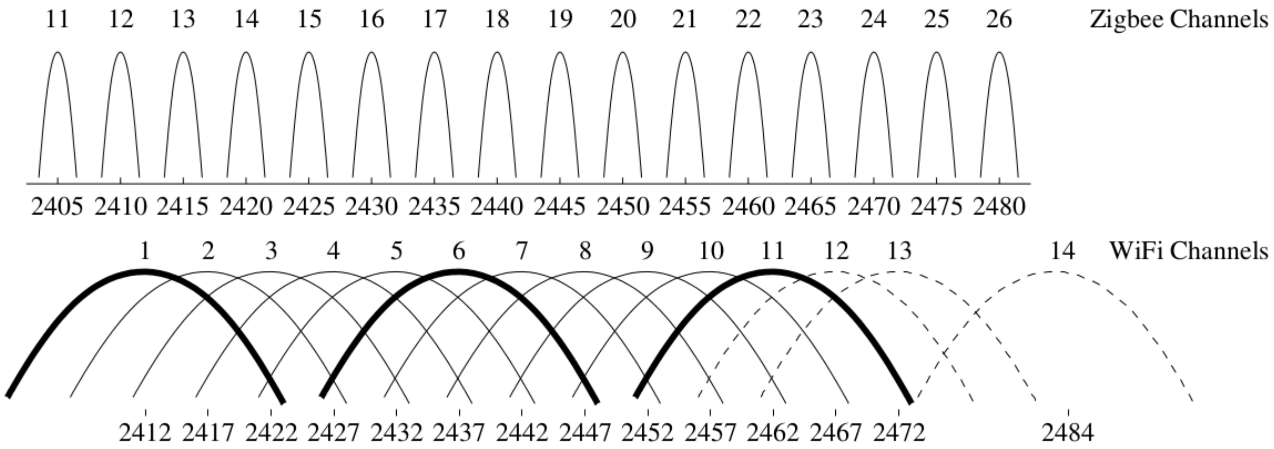
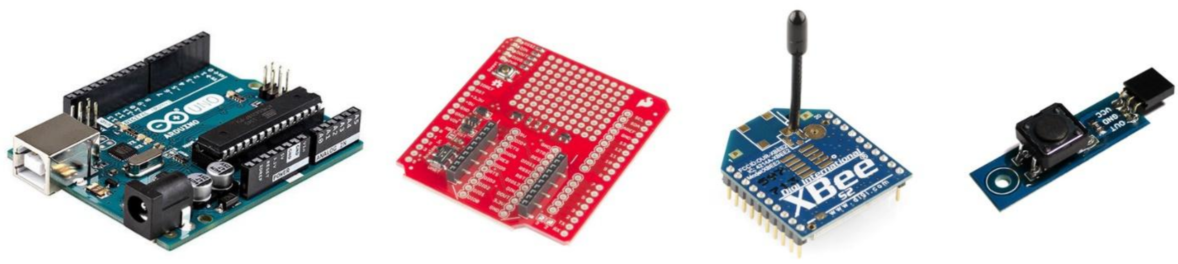


Fig. 1.
ZigBee and Wi-Fi Channels (Liang et al., 2010)

There are many articles and studies that have analyzed the possibility of implementing ZigBee communications in the places where Wi-Fi or other 2.4 GHz wireless communications are already implemented. All of the literature studies revealed the same conclusion regarding ZigBee interferences: the most significant interference is the one produces by Wi-Fi.
Zhao et al. (2014) presented a mixed ZigBee / Wi-Fi communication network that was installed in order to verify the influence of each communication protocol on the other. The tests have been performed both in symmetric (802.11n and 802.15.4 nodes are able to hear each other) and asymmetric (802.11n senders cannot detect 802.15.4 signals) scenarios. The results were that in symmetrical scenario 802.11 networks must work at 40 MHz, but in asymmetrical scenario ZigBee simply cannot be implemented.
Mardini et al. (2012) quantified these findings, testing the effect of increasing ZigBee/Wi-Fi nodes in mixed ZigBee / Wi-Fi communications. The tests have shown a drop in delivery ratio both for ZigBee and Wi-Fi no matter for what network the number of nodes have been increased.
Mangir et al. (2011) have made experiments in noisy and noise-free environment and concluded that the channels 21-24 have packet error rates (PER) of 20-100, while for channels 16, 25 and 26 the determined PER was 0.
Other studies (Crossbow, 2016) have concluded that the percent of received ZigBee packets is, depending on the test performed, between 95.05 and 100%.
Other authors, based on knowledge of ZigBee/Wi-Fi interferences, have tested some solutions to deploy ZigBee without affecting, or being affected by existing Wi-Fi communications: Hou et al. (2009) proposed and tested a method to minimize interferences for ZigBee medical sensors. Huang et al. (2010) have analyzed the possibility of using Wi-Fi white space to deploy a functional ZigBee network.
More radical solutions were proposed by Xu et al. (2011) – to implement multi-channel ZigBee networks that will avoid Wi-Fi interferences, or Youy et al. (2015) to implement a “wise” ZigBee protocol, named WizBee – which solve issues for ZigBee, but not for Wi-Fi.
There were also studies that analyzed the influence of ZigBee communications to Wi-Fi, such as Radunovic et al. (2012), Gummadi et al. (2007), Angrisani et al. (2008), and Wang et al. (2011).

5. ZigBee communication tests

An analysis of communication duration was performed in the laboratory, using the following hardware: one router, two XBee S2 modules, both connected to an Arduino Uno board with an XBee Shield, and one button (Figure 2).



Arduino Uno XBee Shield XBee module Button

Fig. 2.
Hardware components

An XBee 2mW Wire Antenna - Series 2 was used for these tests. The main technical characteristics of this module are: 3.3V @ 40mA needed power supply, 250kbps Max data rate, 2mW output (+3dBm), 120m range, which are good enough for the tests that follows.

One of the XBee modules was set as Coordinator – XB_C and the other was set as End Device – XB_E. XB_E was put into sleep, using Pin Hibernate mode, which means that a digital signal transition from HIGH to LOW on pin 9 of the module (DTR) would wake it up. Both of them were configured to communicate to each other using the parameters presented in Table 4. Parameters not specified in Table 4 will have the default values.

Table 4
XBee Coordinator and End Device configuration

Modified parameters	Coordinator setting	End Device setting
PAN ID	11	11
DH	13A200	13A200
DL	40E779D1	40E922BB
BD	57600	57600
SM		Pin Hibernate

PAN ID (Personal Area Network ID) identifies the network that the device will join. This parameter was changed to avoid joining other possible existing networks.

DH represents the upper 32 bits and DL is the lower 32 bits of the 64 bit destination extended address. Each device was configured with DH and DL of the other device, so they will communicate with each other.

BD represents the Baud Rate, and it was chosen a value sufficient for transmitting necessary data.

SM defines whether the device will have the option to sleep or not. The End Device was set to enter in sleep mode, and to exit it by using a command pin.

The electrical circuit is presented in Figure 3. Pressing the button will determine a LOW to HIGH transition on both pins number 10 of the Arduinos and will have two immediate results: XB_C will start transmitting data and XB_E will be awakened by taking pin 9 (DTR) in a LOW state. The two Arduino boards are connected with a communication cable, necessary to transmit the activation signal from the button and also to keep a distance between modules (in this case was 5 meters). The two resistors are used to establish a known logical level when no triggering signal is available, R1 being a pull-up resistor, and R2 a pull-down one. In order to complete the electrical circuit, the grounds of the two Arduino Uno boards have to be connected.

The tests will focus on determining the time needed for a module to connect to the network and to start receiving data, simulating a connection between an End Device located on-board of a vehicle that enters in the range of a Coordinator, located at the infrastructure level.

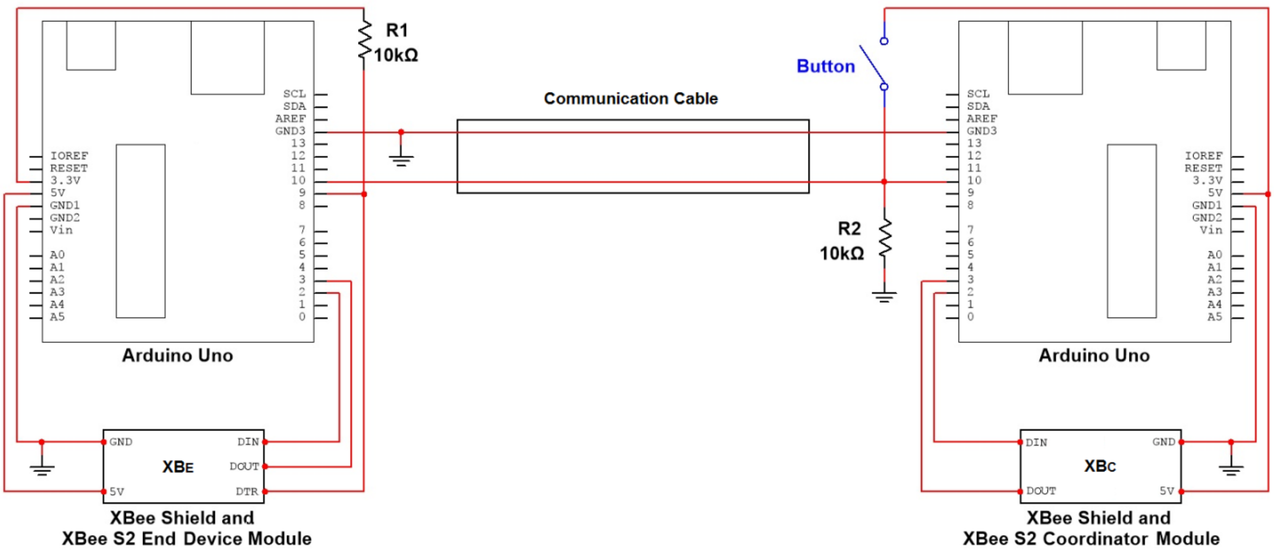


Fig. 3.
Electrical circuit

The testing procedure implied two scenarios:

1. With random Wi-Fi interference (considering that when installing a ZigBee communication network near a road junction it is not possible to know very precise what communications will occur during the network functioning period and, in addition, in the intersections many other signals meet and interfere with each other), and

2. With a router set on the Wi-Fi channel closest to the ZigBee channel that was tested (according to Figure 1) and wireless communication in place (a large file transfer was in progress during this phase of the tests). Hence, the tests have been made for:
    a. ZigBee channel 12 (0x0C), with random Wi-Fi communications and with Wi-Fi communications set on channel 1.
    b. ZigBee channel 17 (0x11), with random Wi-Fi communications and with Wi-Fi communications set on channel 6.
    c. ZigBee channel 22 (0x16), with random Wi-Fi communications and with Wi-Fi communications set on channel 11.
    d. As from other tests (NXP Laboratories, 2013; Digi Wiki, 2014) resulted that ZigBee channels 25 (0x19) and 26 (0x1A) are the ones having less conflicts with Wi-Fi, we have tested these ones with random Wi-Fi communications and with Wi-Fi communications set on channel 13 (the closest Wi-Fi frequency available), but also with Wi-Fi channels 1, 6, and 11 (as being the most frequent channels used).

On transmission start (when pressing the button) XB_C will generate the result of *millis()* function, that returns the number of milliseconds that have passed since the program started running. This value was continuously sent to XB_E. XB_C was set to display the first *millis()* generated at the button press moment and XB_E displayed all the data received and only the first one was considered for comparison. The difference between the two values was calculated:

$$\Delta t = t_{XB_C} - t_{XB_E} \qquad (1)$$

Where; t_{XB_C}: the time indicated by XB_C and t_{XB_C} : the first time indicated by XB_E. The difference between the two values represent XB_E wake up time and connection time (handshake).

$$\Delta t = t_w + t_h \qquad (2)$$

Where; t_w: represents the wake-up time and t_h : the handshake time.
In order to determine the handshake time (the parameters that is of use to us), we have subtracted the wake up time from Δt. t_w is presented in XBee module datasheet (Digi International Inc, 2009), and, for this kind of sleep mode is 13.2 ms. Therefore:

$$t_h = \Delta t - 13.2ms \qquad (3)$$

Additional tests were performed to evaluate the duration of instructions' execution (*millis()* read, variable allocation, data transfer to Arduino Serial Monitor). From these tests it resulted that the total execution time for the programs that have been used is 8 µs, which is negligible.
10 tests have been made for each of the two scenarios. The results of the tests are shown in Figures 4 to 8.

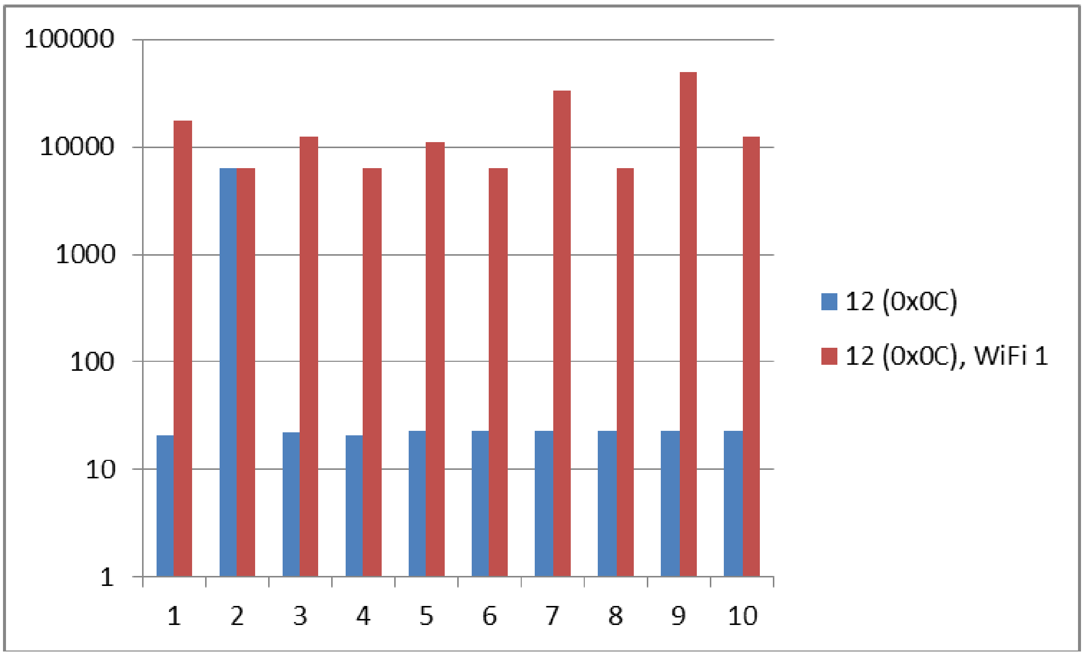


Fig. 4.
ZigBee channel 12 tested in normal conditions and with Wi-Fi communication on channel 1

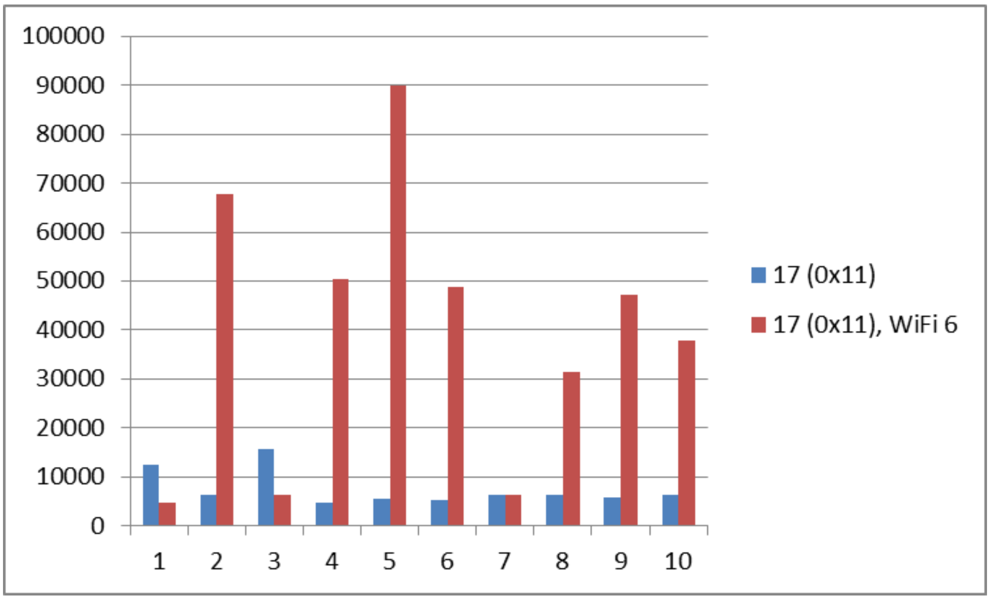


Fig. 5.
ZigBee channel 17 tested in normal conditions and with Wi-Fi communication on channel 6

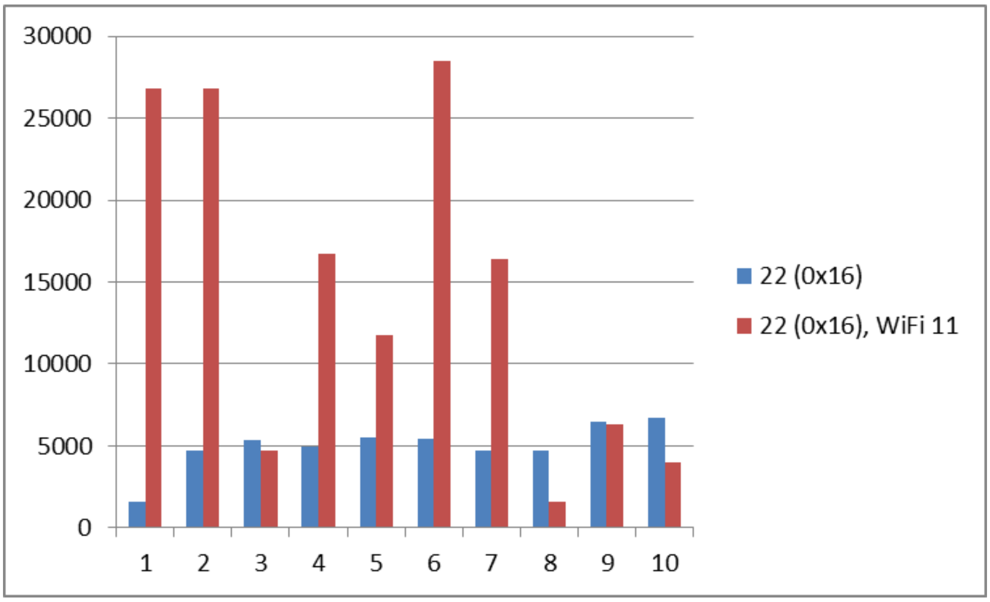
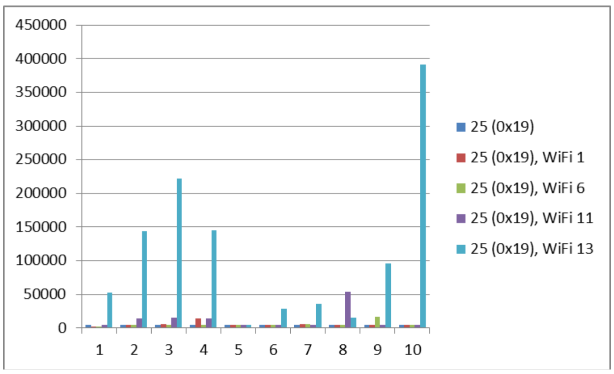


Fig. 6.
ZigBee channel 22 tested in normal conditions and with Wi-Fi communication on channel 11



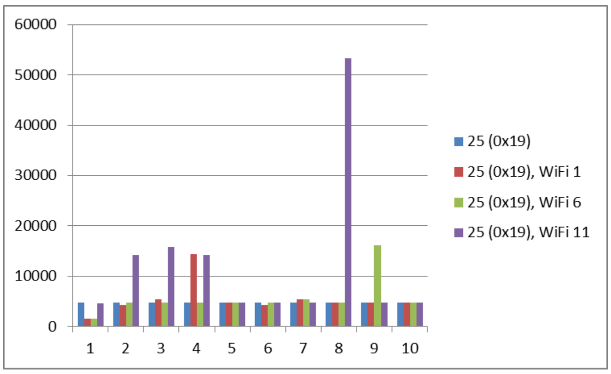


Fig. 7.
a) ZigBee channel 25 tested in normal conditions and with Wi-Fi communications on channel 1, 6, 11, and 13
b) ZigBee channel 25 tested in normal conditions and with Wi-Fi communications on channel 1, 6, 11 for better comparison

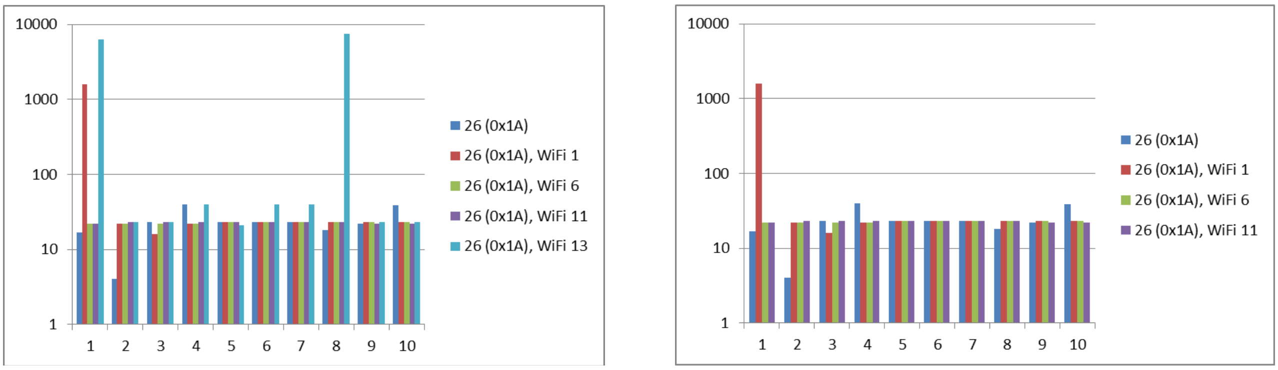


Fig. 8.
a) ZigBee channel 26 tested in normal conditions and with Wi-Fi communications on channel 1, 6, 11, and 13
b) ZigBee channel 26 tested in normal conditions and with Wi-Fi communications on channel 1, 6, 11 for better comparison

From the previous charts we can conclude that there are some values that don't reflect the average situation in a particular scenario. For example, in the last chart there is a spike detected for ZigBee channel 26 when Wi-Fi channel 1 was used to transfer data, but there is only one such case. There is why we have considered that the best method to determine the average situation in the communication would be to calculate the median value of each set. The results are presented in Table 5 below.

Table 5
Median values obtained in tests (milliseconds)

ZigBee channel	Normal conditions	Wi-Fi channel 1 active	Wi-Fi channel 6 active	Wi-Fi channel 11 active	Wi-Fi channel 13 active
12	23	11805.5	-	-	-
17	6293.5	-	42529	-	-
22	5115	-	-	14062.5	-
25	4720	4721.5	4725	4724.5	74082.5
26	23	23	23	23	31.5

6. Conclusion

From the values presented in Table 5 we may conclude the following:

1. ZigBee channels that overlap Wi-Fi channels are heavily affected by Wi-Fi communications,
2. Although channel 12 presents immunity to other random communications, it is disturbed by communications on Wi-Fi channel 1,
3. Channels 17, 22, and 25 present a big handshake latency of more than 4.5 seconds. However, channel 25 presents the same latency in the next 3 tests, proving immunity to Wi-Fi communications on channels 1, 6, and 11. It is only influenced by communications on Wi-Fi channel 13, which has the closest operating frequency,
4. ZigBee channel 26 seems to be the proper solution for implementing ZigBee communications, as it is immune to Wi-Fi communications on channels 1, 6, and 11 and shown only a minor influence by communications on Wi-Fi channel 13.

For the implementation of a ZigBee communication network it is essential to know interferences that may occur. By selecting the proper ZigBee channels and communication parameters, it is possible to implement a new communication network that will ensure a reliable connection, even if some interferences are present. ZigBee is not be the best option if data transfer rate is an issue, other technologies being able to provide much faster data rates. But ZigBee may be a solution for large, new implemented networks (such as access points spread around a whole city or sensor networks), as it is cheap, allows the simultaneous connection of a large number of End Devices to one Coordinator and (also important for large networks) is very effective in terms of energy consumption for all the devices that are connected.
Intelligent Transport Systems are usually based on a large number of sensors acquiring information from different points of the road network, gathering different types of data regarding all the aspects that may be relevant (such as vehicle speeds, traffic density, environmental information, etc.), and transmitting them to the decision factors (like Traffic Management Centers or Traffic and Traveler Information Systems). These sensors may be placed in fixed points, obtaining information only from specific areas, or may be mobile (e.g. placed on public transport vehicles) that are able to gather data from the whole road network, hence providing Traffic Management Centers with a better view of the whole transport system. This communication between mobile devices and road side units usually requires fast connection time (so that a moving vehicle would be able to establish the connection and send the data), low data transfer rates (there are mostly numeric values), and reliability. That is why, we may conclude that ZigBee, if the

network is properly configured, according to the tests performed, may be a proper solution for vehicle to infrastructure communications.

References

Angrisani, L.; Bertocco, M.; Fortin, D.; Sona, A., Experimental study of coexistence issues between IEEE 802.11b and IEEE 802.15.4 wireless networks, *IEEE Transactions on Instrumentation and Measurement*, 57(8): 1514–1523.

Crossbow 2016. Avoiding RF Interference Between WiFi and Zigbee. Available from Internet: <http://www.mobiusconsulting.com/papers/ZigBeeandWiFiInterference.pdf>.

Digi International Inc. 2009. XBee®/XBee-PRO® RF Modules, Product Manual v1.xEx - 802.15.4 Protocol. Available from Internet: <https://www.sparkfun.com/datasheets/Wireless/Zigbee/XBee-Datasheet.pdf>.

Digi Wiki 2014. Zigbee Channels. Available from Internet: <https://www.digi.com/wiki/>.

Gummadi, R.; Wetherall, D.; Greenstein, B.; Seshan, S. 2007 Understanding and mitigating the impact of RF interference on 802.11 networks. In *Proceedings of the ACM SIGCOMM'07*, 385-396.

Hou, J.; Chang, B.; Cho, D.K.; Gerla, M. 2009. Minimizing 802.11 Interference on Zigbee Medical Sensors. In *Proceedings of the Fourth International Conference on Body Area Networks*.

Huang, J.; Xing, G.; Zhou, G.; Zhou, R. 2010. Beyond Co-existence: Exploiting WiFi White Space for ZigBee Performance Assurance. In *Proceedings of the 18th IEEE International Conference on Network Protocols (ICNP)*.

Liang, C.-J. M.; Priyantha, N.B.; Liu, J.; Terzis, A. 2010 Surviving wi-fi interference in low power zigbee networks. In *Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems (SenSys)*.

Mangir, T.; Sarakbi, L.; Younan, H. 2011. Analyzing the Impact of Wi-Fi Interference on ZigBee Networks Based on Real Time Experiments, *International Journal of Distributed and Parallel Systems (IJDPS)*, 2,(4): 1-10.

Mardini, W.; Khamayseh, Y.; Jaradatand, R.; Hijjawi, R. 2012. Interference Problem between ZigBee and WiFi. In *Proceedings of the IACSIT Hong Kong Conferences IPCSIT*.

Minea, M.; Badescu, I.; Dumitrescu, S. 2011. Efficiency of Multimodal Real-Time Travel and Traffic Information Services Employing Mobile Communications. In *Proceedings of the 10th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services IEEE Proceedings*, 765-769.

Minea, M.; Dumitrescu, S. 2009. Vehicle to Infrastructure Communications – Technologies and EMC Problems in Public Transport Management System. In *Proceeding of IEEE 9th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services*, 453-457.

NXP Laboratories 2013. Co-existence of IEEE 802.15.4 at 2.4 GHz. Application Note. Available from Internet: <http://www.nxp.com/documents/application_note/JN-AN-1079.pdf>.

Radunovic, B.; Chandra, R.; Gunawardena, D. 2012. Weeble: enabling low-power nodes to coexist with high-power nodes in white space networks. In *Proceeding of CoNEXT*, 205-216.

Sikora, A.; Groza, V.F. 2005. Coexistence of IEEE 802.15.4 with other Systems in the 2.4 GHz-ISM-Band. In *Proceedings of the IEEE Instrumentation and Measurement Technology Conference*, 1786-1791.

Wang, Y.; Wang, Q.; Zeng, Z.; Zheng, G.; Zheng, R. 2011. Wicop: Engineering WiFi temporal white-spaces for safe operations of wireless body area networks in medical applications. In *Proceedings of the RTSS '11*, 70-179.

Xu, R.; Shi, G.; Luo, J.; Zhao, Z.; Shu, Y. 2011. MuZi: Multi-channel ZigBee Networks for Avoiding WiFi Interference. In *Proceedings of the IEEE International Conferences on Internet of Things, and Cyber, Physical and Social Computing.*

Youy, L.; Yangx, P.; Chen, G. 2015. WizBee: Wise ZigBee Coexistence with WiFi via Interference Cancellation, *IEEE Transactions on Mobile Computing*, 14(12): 1-10.

Zhao, Z.; Wu, X.; Lai, X.; Zhao, J.; Li, X.Y. 2014. ZigBee vs WiFi: Understanding Issues and Measuring Performances of IEEE 802.11n and IEEE 802.15.4 Coexistence. In *Proceedings of the Performance Computing and Communications Conference (IPCCC).*

ZigBee Alliance 2007. ZigBee and Wireless Frequency Coexistence, ZigBee White Paper - June 2007, Available from Internet: <http://www.zigbee.org>.

ZigBee Alliance 2016. ZigBee specifications. Available from Internet: <http://www.zigbee.org>.

REQUIREMENTS FOR A PRO-ACTIVE COOPERATIVE CRUISE CONTROL STRATEGY EMPLOYING VEHICULAR AD-HOC NETWORKING

Marius Minea[1]
[1] *University Politehnica of Bucharest, Transports Faculty, Bucharest, Romania*

Abstract: The paper makes an analysis on the requirements for a pro-active and cooperative cruise control strategy, based on vehicular ad-hoc networking (VANET) and designed for highway traffic safety management. The algorithm is used to dynamically provide cruising information to vehicles, grouped in a self-organizing cluster. A fast responsive component alerts vehicles if an abnormal traffic event is detected. Each vehicle running the algorithm should be aware and adaptive to the local traffic and communication conditions. Priority is given to alert messages with the role to warn vehicles' drivers of a possible collision, in case of a hard braking of a vehicle, or in case a vehicle rapidly changes heading (yaw). Recommended vehicle-to-vehicle (V2V) communication protocols are also investigated, and a solution based on a self-adaptive clustering algorithm is proposed. The average vehicle headroom, speed and acceleration patterns are analyzed for the local vehicle cluster and a weighted control function (WCF) is built by the algorithm. Taking into account the dynamic environment, appropriate cruise values (velocity and headroom) are used to inform the driver. According to different priority degrees, messages are delivered with the lowest delay possible to all vehicles in the area of interest. The clustering algorithm also takes into consideration an optimal modality to group vehicles in a cluster according to their relevance to the message. Finally, an analysis of the quality of service is performed taking into account parameters such as traffic density and unreliable radio coverage.

Keywords: pro-active cruise control, adaptive clustering algorithm, delay tolerance, weighted control function.

1. Introduction

Road traffic is nowadays in a continuous expansion and essential for any developing society. However, vehicular traffic is frequently subject to accidents, mainly due to the large presence of vehicles and heterogeneous types of drivers, flowing on under-dimensioned and insufficiently adapted road infrastructures. Intelligent transport systems (ITS) are applications aimed at improving traffic safety by delivering appropriate in-time information to traffic participants. One of such applications is the cooperative cruise control with vehicle-to-vehicle communications without infrastructure support, such as Dedicated Short-Range Communications (DSRC). Related applications in the ITS infrastructure that deal with traffic management usually require deployed static sensors in order to acquire traffic and environmental information. Collision warning systems are built for highways, where the speed of vehicles is high and a potential collision may lead to serious injuries or even fatalities. Therefore, the development of cooperative cruising control solutions is highly imperative. The installation, maintenance and exploitation of numerous sensors in a highway infrastructure is, however, expensive and energy-consuming. Recent applications of DSRC came with more advantageous solutions, such as the employment of vehicles as "traffic moving sensors" (or "floating cars"). Collecting and managing data, algorithms and quality of service (latency, throughput, jitter) is, however, not an easy task, because cooperative collision warning systems (CCWS) are mostly non-delay tolerant to safety messages.

2. Literature Review

This section presents state-of-art in the field of cooperative cruising/warning solutions employing VANET algorithms, based on a literature study.

2.1. Cooperative Collision Avoidance - Dynamic Information Processing

The detection of a traffic incident is usually a simple task for the actual advanced traffic information and management systems. Parameters such as: speed, flowing and/or density are usually taken from sensors processing each lane of the highway. Secondary parameters, like vehicle lengths, weights etc. may be used for vehicle classification or other functionalities. If an improper behavior is detected, the system may trigger a traffic event alert. Specific algorithms are employed to correctly distinguish between normal and abnormal traffic behaviors. Some authors (Lee J. and Park B, 2012) assume a connected vehicles environment to create a cooperative vehicle intersection control for improved traffic management. Recent advances in traffic safety employ cooperative driving based on DSRC - such a solution is presented by Amoozadeh, M. et al., 2015. The platooning of large trucks helps in building a common safety approach in driving the vehicles, by maintaining appropriate headroom between each vehicle in the cluster. An interesting approach for traffic safety is suggested by Van der Horst and Hogema, 2013, where time-to-collision (TTC) is defined as a measurement parameter for discriminating normal from critical traffic behavior and sending collision warnings. The authors specify that an important issue in developing collision avoidance systems would be to define a proper warning strategy, acting *only when the driver is really at danger* and immediate action is required. Errors should be avoided, as too many false alarms may easily cause the system to become a nuisance to drivers. Yang et al. (Yang, 2004) consider

[1] Corresponding author: marius.minea@upb.ro

an "abnormal vehicle" such a vehicle that is subject to a mechanical failure, or brakes hardly due to unexpected road hazard and decides to broadcast a warning message to its neighboring vehicles. However, the neighboring vehicles do change very rapidly positions in a real traffic scenario, and to deliver reliably warning messages over unreliable radio networks needs repeated transmissions. Chen (Chen et al., 2010) showed that vehicle mobility patterns caused by varying traffic dynamics and driving behavior may lead to considerable complexity in the efficiency and reliability of vehicular communication networks.

2.2. Radio Connectivity and Quality of Service in VANET

DSRC employs channel bands in the 5.9 GHz band dedicated for safety and non-safety applications. The draft version of the DSRC lower medium access control (MAC) and physical layer (PHY) was published as part of the IEEE 802.11p amendment standard in 2010 for wireless access in vehicular environment. Cassidy (Cassidy, 2013) investigates a cross-layered design for improved vehicular safety messaging. One known problem of dense vehicular environments is message collision that occurs when too many vehicles attempt to simultaneously broadcast. The broadcasting frequency, which depends on traffic density and number of repetitions, corroborated with vehicle mobility, can strongly affect the quality of service and reduce the probability of successful message reception. The message delay for safety applications is also important, and the IEEE 802.11p specification has set a minimum allowable latency of 100 ms for periodic message broadcasts (Chen, 2010). Ghafoor (Ghafoor and Mohamed, 2013) investigates and evaluates the most known protocols for VANET in dense vehicular environments, recommending VADD (Vehicle-Assisted Data Delivery) and SRR (Stability and Reliability Routing) protocols. Nagaraj et al. emphasize that in urban areas, a very bandwidth efficient protocol is Edge-Aware Epidemic Protocol (EAEP) as it reduces the control packet overhead by eliminating exchange of additional "hello" packets for message transfer between different clusters of vehicles. Urban areas are not favorable to radio communications. High density of structures is obstructing direct propagation, or reducing the range of radio signals. The environment is also flooded with signals from dense and various local access points. In this regard, distinctive VANET networking properties are analyzed in (Rievaj et al., 2013), where Rievaj described the main design decisions in building algorithms for these networks. An adapted design of network challenges is presented in figure 1 below.

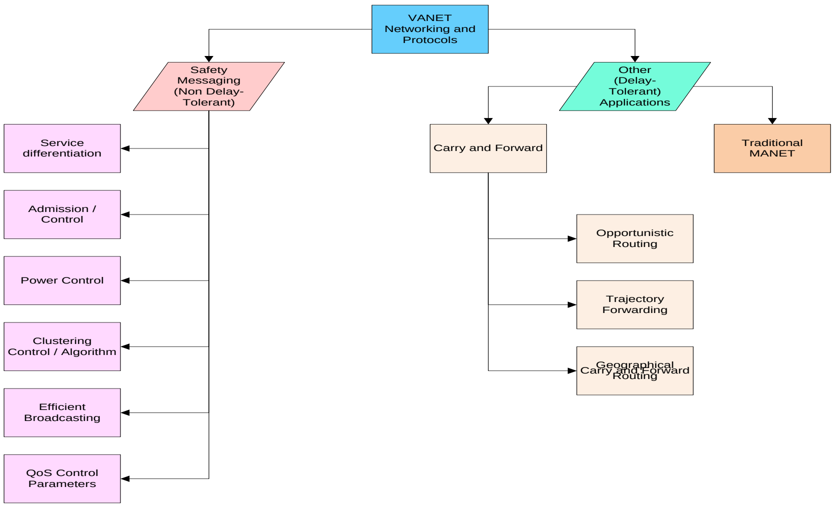


Fig. 1.
Risk factors in assessing VANET performances in a QoS analysis

When selecting a specific protocol for a CCWS application, the following features are important: service differentiation (messages priorities), rules for nodes clustering, power control for limiting cluster boundaries, rules for application-specific clustering to obtain efficient warning messages broadcasting (with reduced collisions and bandwidth consumption) and a firm control of service quality. Yousefi presented elements that should be taken into account for CCWS applications:

- Frequent fragmentation of network,
- Small effective diameter of the network and rapid changes in links' connectivity, causing frequent path disconnections,
- In dense urban areas, the lack of power constraints, leading to interferences with nodes out of interest,
- Widely variable network density - in direct correlation with vehicular density
- Driver behavior affecting of network's topology, and his/hers reaction to received messages. A positive aspect is when the driver behavior can be alleviated to improve traffic safety (by selecting adequate content and moments to deliver messages), while the negative aspect is when critical safety messages arrive in improper moments and may lead to traffic turbulences.

3. Main Factors for a Safe Driving Control Function

In order to make vehicles aware of the traffic environment, the following elements are essential in the design of a system employing dynamic information:

- Velocity and acceleration of cars,
- Average headroom in the lane (in relationship with vehicle density, relative speed and relative acceleration),
- Rate of turning.

In the following, a brief analysis on these factors is undertaken and the components to build a control function are deducted.

3.1. Influence of Vehicles' Velocity and Acceleration

Vehicle's velocity has a major influence on the braking distance. The control function in CCWS should provide a dynamical estimation of the minimum braking distance. Assuming driver's reaction time to external stimuli is ignored, other factors may influence the braking distance: the mass and technical condition of the vehicle, the quality of road surface, weather condition, tires inflation, rolling surface profiling, presence and efficiency of the Anti-lock Braking System (ABS) etc.. Let us denote these as *random conditions*. Defining a mathematical model for the majority of these elements is difficult, or even impossible. Additional coefficients with a certain degree of randomness should be used instead. A commonly agreed contribution of speed at the braking distance until complete stop is described by the following formula:

$$d_F = d_r + \xi_c \cdot d_s \tag{1}$$

Where; d_F : distance to full stop from the observation of the event, d_r : distance traveled by the vehicle during driver's time to react, ξ_c : a random factor that takes into consideration conditions afore mentioned, d_s : skid distance. The skid distance may be, in these conditions, considered in direct interdependence with the vehicle's velocity :

$$d_s = v_s \cdot t_s \tag{2}$$

Where; v_s : initial vehicle speed at the moment of braking, t_s : time until full stop.
Some U.S. regulations assume that an appropriate methodology for determining the initial speed when the braking mark is measurable is to consider an initial test speed for which the effective skidding distance is measured, and then employ the formula:

$$v_m = v_t \cdot \sqrt{\frac{d_s}{d_{st}}} \tag{3}$$

Where; v_m : minimum initial speed, v_t : a previously measured speed for which the d_{st} distance to full stop is known. Replacing these values in (1) gives:

$$d_F = d_r + \xi_c \cdot d_{st} \frac{v_m^2}{v_t^2} \tag{4}$$

This assumes that an initial table with d_{st} and v_t measured and corrected values is available. Considering in more details the elements that contribute to the braking distance, Rievaj et al. in [9] suggested another relationship:

$$d_F^a = (t_r + t_o) \cdot v + v \cdot t_N - \frac{a_N \cdot t_N^2}{2} + \frac{v_N^2}{2a} \tag{5}$$

Where; d_F^a : distance to full stop, considering the variable deceleration during braking, t_r : driver response time, t_o : delay time to effective braking, due to the brakes, t_N : increased time for braking due to vehicles equipped with hydraulic brakes, v : initial velocity of vehicle, v_N : reduced value of speed due to braking deceleration, a_N : braking deceleration of the vehicle during braking increasing, a : full average braking deceleration.
Due to the fact that $d_r = (t_r + t_o) \cdot v$, the formula (5) becomes:

$$d_F^a = (t_r + t_o) \cdot v + v \cdot t_N - \frac{a_N \cdot t_N^2}{2} + \frac{v_N^2}{2a} \tag{6}$$

and considering the random factor ξ_c, a more usable relationship will be:

$$d_F^a \cong d_r + \xi_c [v \cdot t_N - \frac{a_N \cdot t_N^2}{2} + \frac{v_N^2}{2a}] \tag{7}$$

The variable acceleration is measurable with onboard sensors. Therefore, the algorithm should take into consideration equation (4) if such these are not present onboard, or equation (7) if acceleration values are available to system.
If the vehicle is also equipped with an inclination sensor, then a coefficient to correct safety braking distance according to road gradient (in percent) is given by:

$$\delta_g = d_F^a(-\frac{g}{a+g}) \tag{8}$$

Where; δ_g : grade correction coefficient in braking distance, g : the grade coefficient in percent, with $g > 0$ meaning upgrade and $g < 0$ downgrade.

3.2. Influence of Traffic Density and Road Curvature

Regarding the distance that separates vehicles, also known as headroom, it is important to consider that increasing speed of vehicles needs increased headroom, in order to keep a minimum safety distance for collision avoidance. Therefore, traffic density contributes in the calculation of the weighted control function for collision warning. The safety distance between platooning vehicles is also known as *Assured Clear Distance Ahead*, or ACDA, which is mandatory, but sometimes not enough in evaluating the basic speed law[2]. As the solution proposed here does not take into consideration organic observations of the driver, like direct seeing of the event, but instead triggers a warning when the control function components overcome certain thresholds (all values provided only by equipment sensing), the ACDA may be determined in a simpler mode, as function of the appropriate time gap and the operating speed:

$$d_{ACDA} = t_h \cdot v \tag{9}$$

Where; d_{ACDA} represents ACDA when time t_h necessary to the following vehicle to reach the leading vehicle at measured speed v may be computed. Of course, as in the case of equation (4), some unknown variables still remain, such as relative speed and acceleration patterns between the following vehicles. Below a certain distance between vehicles, the movement pattern becomes dependant on the leading vehicle, that is all vehicles that fall under this condition become part of a platoon, behaving in interdependency. Therefore, vehicle platooning should be taken into consideration, when computing the ACDA. This might be derived from the distance to neighboring nodes. For determining the traffic density, the road section may be divided in homogenous cells, of length l_c, indexed by i, an integer that increases in the direction traffic is traveling. Traffic is sampled at each τ time units. Let then $N_v(t)$ be the number of vehicles lying in cell i in the interval $(t, t+\tau)$. We assume the cell length is similar with the radio propagation radius. That is roughly few hundred meters, as in terms of transmitted power, four classes of devices have been defined, whose maximum power ranges from 0 dBm to 28.8 dBm. In the time-space areas where the traffic density is stable, the density $\delta_i(t)$ of vehicles in cell i of length l_c is:

$$\delta_i(t) = \frac{n_v(\tau)}{l_c} \tag{10}$$

Where; $n_{vi}(\tau)$ is the number of vehicles in cell i. The length of the cluster l_c is determined by computing the distance to the most distant neighboring nodes within the communication range. The density component of the weighted control function D_f is then:

$$D_f = \frac{\sum_{l=1}^{n_l} \sum_{v=1}^{n_v} \{v_{l,v}(z) \in C\}}{\sum_{l=1}^{n_l} l_l} \tag{11}$$

with: $v_{l,v}(z) \in C$: vehicles detected in the range of the local cluster C, (onboard computing), l_l : length of lanes in the cluster $(l_l = l_c)$, n_l the number of lanes and n_v the number of vehicles.
In determining headroom, Private Car Units (PCU) may be employed, instead of real vehicle lengths. The average headroom in the cluster becomes:

$$d_F^p = l_c - \xi_3 n_{PCU} l_{PCU} = l_c - \xi_3 l_c \delta_i(t) l_{PCU} = l_c(1 - \xi_3 \delta_i(t) l_{PCU}) \tag{12}$$

Where; d_F^p : average computed headroom, ξ_3 : correction factor describing the real vehicle traffic composition (i.e. percent of small cars in the traffic), n_{PCU} : equivalent number of PCUs in the cell of length l_c, l_{PCU} length of a PCU. Relative acceleration and speed may be considered only if onboard equipment is able to determine by measurement these values. For the speed limitation due to road curvature a common relationship is:

[2] Usually determined in U.S. regulations for road safety

$$v_{RC} \approx \sqrt{\frac{gr(\mu + e)}{1 - \mu e}} \tag{13}$$

with: v_{RC} : the safety limiting speed due to road curvature, g : gravitational acceleration, r : radius of the road curvature, μ : friction coefficient. This must be taken into consideration by the algorithm determining the safety limit speed when the road cell is situated in a curvature.

4. Defining the Clustering Strategy and the Weighted Control Function

The vehicle clustering strategy should be dynamic, taking into consideration the following factors: *communication distance*: the cell dimension (area where clustered vehicles are included) should be kept reasonable small, in order to maintain a clear radio coverage and reduce the interferences, while still enough large to encompass the platooning vehicles that are to be alarmed in case of emergency; rules for including neighboring vehicles (nodes) in the cluster:

- *only vehicles traveling in the same direction;*
- *only vehicles behind the alert message originator;*
- *group and maintain in the cluster only neighboring vehicles that have a relative speed within a certain threshold (eliminate from the cluster those vehicles that travel much faster or slower than the considered sourcing vehicle);*
- *vehicles traveling on other lanes, but in same direction; vehicles traveling in reverse direction are not to be considered for clustering.*

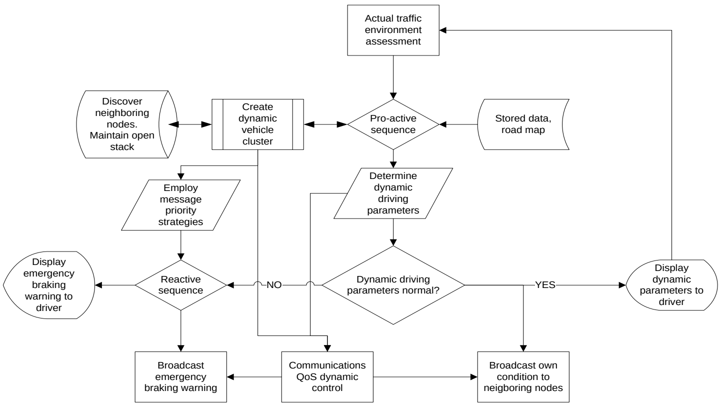


Fig. 2.
Vehicle clustering strategy and associated algorithm

The weighted control function is used to dynamically estimate and control the safety conditions in a given cluster, of given dimensions. This process results in the information provided to drivers (speed and headroom to their leading vehicles), representing the *pro-active sequence of the strategy*. The control function is based on vehicle speed, cluster's density of traffic and acceleration. If one of the alarm conditions is reached, then the algorithm should broadcast an emergency braking warning (the *reactive sequence of the strategy)*: (*i*) - receiving a relevant emergency braking alarm message from leading vehicles, (*ii*) - detecting deceleration/speed rapid variation, (*iii*) - detecting rapid variations in vehicle's horizontality or horizontal angle.

The algorithm may act in the following sequence:

- *read vehicle position; determine limiting speed due to road curvature (electronic map) - equation (13);*
- *discover/determine the number of neighboring vehicles that fit in the local cluster according to rules and reject other received vehicles that should not belong to cluster; isolate and reject vehicles running in opposite direction; perform intra-group networking to support communications;*
- *determine optimal length of the cluster l_c by computing the distance to the most remote neighboring node within the defined cluster; allocate messages priorities according to distances to neighboring nodes;*
- *compute average headroom in the cluster (equations 11,12);*
- *compute and evaluate the logical weighted control function components for safety speed limit and headroom; - determine recommended speed and average headroom in the cluster, based on computed WF:*

$$\begin{aligned} V_{WCF} &= \min\,\{v_m \vee v_{RC}\} \\ d_{WCF} &= \max\,\{d_F^p \vee d_{ACDA}\} \end{aligned} \tag{14}$$

- *display to the driver the computed (recommended) speed and headroom values V_{WCF}, d_{WCF};*
- *compare control function parameters to imposed thresholds:*

$$V_{WCF} \geq \theta_v;\ d_{WCF} \leq \theta_d \tag{15}$$

- if any alarm thresholds θ_v, θ_d in (15) is reached, warn the driver regarding unsafe driving conditions; display warning only if:
- driver did not previously take cautious measures by reducing speed or headroom;
- there is still enough time to collision or there are too frequent changes between alarming and non-alarming states (i.e., the vehicle is driven at the limit of the potential dangerous conditions) - this contributes to reducing driver stress;
- if at least one of the emergency conditions (i) to (iii) is triggered, then warn the driver of emergency braking and broadcast emergency message to relevant nodes in the cluster.

5. Analysis of Communication Efficiency

In this section a brief analysis of usable VANET protocols, taking into account the radio environment, is provided. The study is performed both for urban and extra-urban environments.

5.1. Influence of Traffic Density over Network Connectivity

Traffic density is an important factor influencing network connectivity and QoS. In low traffic densities, network connectivity has frequent interruptions, due to larger distances between communicating nodes (vehicles). Therefore, the communication protocols should be able to memorize messages and forward them when possible. However, in low traffic densities safety is higher, as no close neighboring vehicles are surrounding the central node. Consequently, the pro-active strategy (recommended safety speed and headroom information) ensures an acceptable level of traffic safety. Figure 3 presents the network connectivity vs. flow-density diagram.

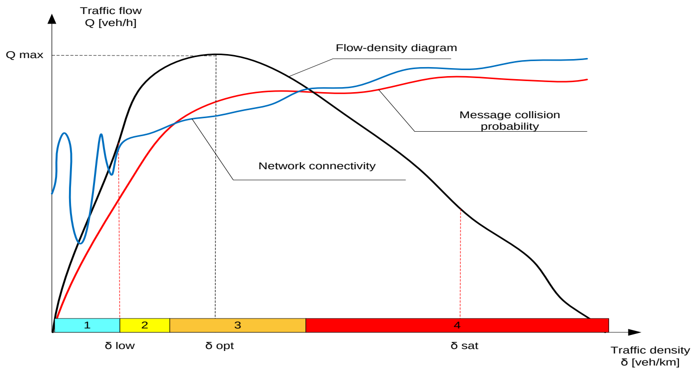


Fig. 3.
Connectivity and message collision probability in assessing traffic-related VANET performances (extra-urban environment)

Usually, geographical routing protocols of VANET are recommended for fast responsive messaging. However, in high connectivity areas, where the probability of an incident decreases with lower speeds, topological routing protocols may be also employed. In figure 3 the behavior of network connectivity and message collision probability versus the traffic density of vehicles is presented. In this respect, it becomes possible to define four interest areas (presented in colors: green, yellow, brown and red):
- *1 (green) - low connectivity / probability of message collisions, due to low traffic density and large gaps between neighboring vehicles. Vehicles move freely, with no interdependency. Average speed is high and in interurban areas the probability of message collisions and/or interferences is low; in this case, geographical routing protocols such as GeOpps (Geographical Opportunistic Routing) or VADD (Vehicle Assisted Data Delivery) are recommended, due to the fact that they allow for memorization and forwarding of messages;*
- *2 (yellow) - interdependency of vehicles' movement become dominant and average speed lowers. Vehicles are driven in platoons. Network aggregation is better, but message collisions may occur; VANET geographic routing protocols such as TBF (Trajectory Based Forwarding) or MoVe (Motion Vector scheme) are recommended, because they use beaconing and geographical/dynamic node data to forward/broadcast messages in a single hop;*
- *3 (brown) - nominal conditions. The flowing of vehicles is at peak and the road level of service is maximum. Connectivity is best and message collision probability is high. Special communication protocol measures have to be undertaken to cope with message collisions; same VANET protocols as in -2 are recommended for this area of interest; polling techniques should also be employed to maintain acceptable network throughput;*
- *4 (red) - congested traffic. Traffic flowing reaches road capacity. Vehicle speed is largely variable due to frequent stopping of vehicles. Connectivity and message collision probability are highest. Severe anti-message collision measures have to be undertaken. Polling (dynamically reduced frequency of beaconing) should be employed to lower network bandwidth overloading. Moreover, VANET protocols with dynamic content of messaging and reduced set of communication beaconing to maintain the link should be employed, e.g., FSR (Fisheye State Routing).*

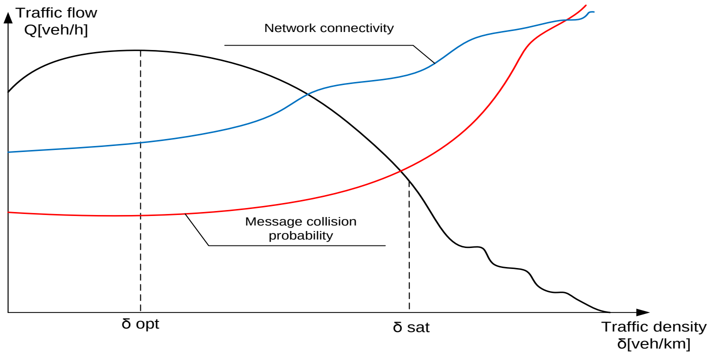


Fig. 4.
Connectivity and message collision probability in assessing traffic-related VANET performances (urban environment)

In urban environment (figure 4), the probability of message collisions is much higher, due to the presence of supplementary access points and higher traffic density. The VANET protocols should employ polling techniques combined with intensive local computation of interest parameters, a dynamic selection of messages to be broadcasted, in order to minimize the network overloading.

5.2. Quality of Service Analysis

There are some important issues regarding the radio link between communicating nodes: the frequent path disruptions caused by the high vehicles' mobility and frequent message collisions in dense traffic areas, where network throughput is affected. Therefore, the communication protocol should be able to predict link interruptions, according to vehicles' trajectory estimation and to reduce the network flooding for requests by prolonging the link durations only on selected paths.

5.2.1. Message Delay Tolerance

In the normal operation of the proposed strategy, there is a specific attribute that broadcasted messages should bear, that is the tolerance to delaying: only normal messages should be delay-tolerant and not emergency ones. Therefore, the "normal status" beaconing messages should fall under the following rules:

- *may employ routing protocols with higher communication distances;*
- *may employ dynamic polling broadcasting techniques with network throughput control in dense traffic areas;*
- *may employ communication protocols such as carry-and-forward, if network connectivity is reduced.*

"Emergency" warning/braking messages should:

- *be as short as possible;*
- *support one-hop broadcasting in dense networks and multi-hop strategies broadcasting for reduced connectivity cases;*
- *use geographical and fast-responsive routing protocols for limiting boundaries of the cluster.*

The total estimated delay Δ_{EWM} for an emergency warning message (EWM) is:

$$\Delta_{EWM} = \delta_d + \delta_s + \delta_{NP} + \xi\delta_C + \delta_E \tag{16}$$

with: δ_d - time to discover neighboring nodes / build the dynamic stack; δ_s - time to select relevant nodes, candidate for receiving EWM, according to message priority strategy (described in Section 4); δ_{NP} - total delay recorded in the network transmission process; ξ - random factor dependant on the nodes density in the network; δ_C - additional delay induced in dense radio environments, due to frequent message collisions; δ_E - time between effective event occurrence and the moment when the information becomes available for processing in the onboard unit. For a speed of *v=140* km/h, a vehicle travels 3.8m in 100 ms, and needs around $d_{FS} = \frac{v^2}{2\mu g}$ meters until full stopping, with μ the actual friction coefficient. Therefore, taking into account equation (16), the total stopping becomes:

$$d_{FS}^T = d_{P-R} + v \cdot \Delta_{EWM} + d_{FS} \tag{17}$$

with d_{P-R} - the distance traveled by the vehicle from the moment the driver notices the warning message until he/she triggers the braking. For collision avoidance, the condition is that the overhead from the leading vehicle is:

$$d_{FS}^T < d_F^p \tag{18}$$

Concluding, the maximum EWM delivery time shall be no greater than $\frac{d_F^p}{v}$.

5.2.2 Beaconing Frequency versus Capacity

In normal operation (no EWM beaconing), the main problem is to keep under control the network overload with an adequate message beaconing policy. Li, Y. showed that, in order to minimize the air time overhead, longer frames are preferable, and gave an estimation of the number of vehicles that can simultaneously co-exist in the coverage area of a single link radio system (table 1 below).

Table 1
Network capacity over maximum number of frames sent

Duration of payload [μs]	Minimum overhead ratio [%]	Maximum number of frames sent
98	100	234
196	50	156
294	33.3	117
392	25	93
490	20	78
588	16.7	67

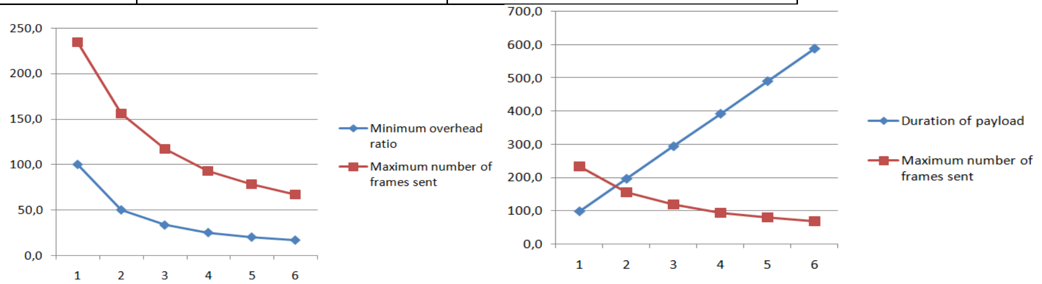


Fig. 5.
Parameters for beaconing frequency analysis

For the presented CCWS strategy, the objective is to maintain the vehicle driver dynamically informed, so key metrics should include beacon delivery ratio, number of consecutive message lost between pairs of vehicles, reliability, overhead, speed of data dissemination, and reception probability. As a larger communications range potentially increases the number of nodes contenting for the channel, which may significantly degrade the chance of successful packet delivery, the strategy should make use of local clustering algorithm to limit the boundaries of participating nodes at a certain domain, maintaining in this way the control of packet collisions.

6. Conclusions and Future Research

The paper proposed an approach for a pro-active, cooperative cruise control strategy for improving traffic safety on highways. The strategy employs local vehicle sensing of dynamic parameters and cooperative cruise control messaging with different communication protocols in DSRC. A preliminary analysis on the network connectivity and influence of traffic density has also been performed. The next step will be to verify the components of this strategy within different physical network environments. Measurement of communicating nodes density in different (urban and extra-urban areas) is under development. As an initial support, computer modeling and simulation will be the primary tools for verifying the research results.

References

Amoozadeh, M.; Deng, H.; Chuah, C-N.; Zhang, H.N.; Ghosal, D. 2015. *Platoon Management with Cooperative Adaptive Cruise Control Enabled by VANET*. Elsevier Vehicular Communications 2.

Cassidy, W. 2013. *MAC/PHY Cross-Layer Design for Improved Vehicular Safety Messaging Reliability and Simulation Environment Design*, ETD, University of Windsor, UK.

Chen, R.; Jin, W-L.; Regan A. 2010. *Broadcasting Safety Information in Vehicular Networks: Issues and Approaches.* IEEE Network, January/February, 0890-8044/10.

Ghafoor, K.Z.; Mohammed, M.A. 2013. Routing Protocols in Vehicular Ad hoc Networks: Survey and Research Challenges, *Network Protocols and Algorithms*, 5(4): 45.

Lee, J.; Park, B. 2012. Development and Evaluation of a Cooperative Vehicle Intersection Control Algorithm under the Connected Vehicles Environment, *IEEE Transactions on Intelligent Transport Vehicles*, 13(1).

Nagaraj, U.; Dhamal, P. 2012. *Broadcasting Routing Protocols in VANET*. Network and Complex Systems, 1(2).

Rievaj, V.; Vrabel, J.; Hudak, A. 2013. The Inflation Pressure Influence on a Vehicle Stopping Distances, *International Journal of Traffic and Transportation Engineering*, 2(2): 9-13.

Van der Horst, R.; Hogema, J. 2012. Time-to-Collision and Collision Avoidance Systems. In *Proceedings of the 6th ICTCT International Cooperation on Theories and Concepts in Traffic Safety*.

Yang, X.; Liu, J.; Zhao, F.; Vaydia, N.H. 2004. *A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning*. In *Proceedings of the First Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services*.

A SURVEY ON VEHICULAR AD-HOC NETWORK COMMUNICATIONS EFFICIENCY IN DENSE URBAN TRAFFIC SCENARIOS

Marius Minea[1], Maria Claudia Surugiu[2], Ion Nicolae Stăncel[3], Badescu Iulian[4]
[1,2,3,4] Telematics and Electronics for Transports Department,"Politehnica" University of Bucharest - Transports Faculty, Bucharest, Romania

Abstract: Nowadays vehicular technologies are heading towards safety thru information exchange and autonomy. Vehicular Ad-Hoc Networks (VANET) have been recently developed for traffic safety and information transmissions in the idea of eliminating the need of a fixed infrastructure network. However, their efficiency in very dense urban traffic scenarios is still arguable, due to frequent message collisions, reduced throughput and other quality of service - related problems, encountered when traffic density exceeds certain thresholds. This paper presents a survey on mobile VANET efficiency in these conditions, where the radio environment is affected by the large number of mobile nodes and also by numerous local WiFi access points. A case study for some congested junctions in Bucharest is used to analyze the channel utilization in IEEE802.11 standards. An algorithm to improve the efficiency and service quality in vehicular communications is proposed. A-VANET, or Assisted-VANET, is the combined communication technology introduced by this paper, in order to ease the transfer of non-critical messages in dense vehicular scenarios.

Keywords: VANET protocols, vehicular and wireless technologies, traffic control.

1. Introduction

Recent developments in wireless communication technologies allow for the creation of a new outline for vehicular ad-hoc networks. In a VANET network, vehicles, as communication nodes, are able to share data or send messages via multi-hop pathways, using intermediary vehicles to reach a destination node. The routing protocol must find a path between the source and the destination to establish a data link. Implementing a protocol requires care in network quality of service; some applications also may need delay tolerant protocols, in order to ensure a safe transmission. By reducing the number of vehicles via which messages are sent, data traffic may be also diminished, facilitating a performance boost and eliminating network congestion. Given that it is build on vehicles routes' information, the message will be directly sent to nodes heading for the destination, thus reducing overall delivery time. Broadcast / multicast transmission is a mechanism often used to disseminate information from the source node to a destination node group. User authentication, network participants confidentiality and message integrity are the required elements for a safe messages exchange.

Some of the most important aspects in recent developments related to Intelligent Transport Systems (ITS) are those based on mobile communication between vehicles (V2V) and between vehicles and infrastructure (V2I), and vehicle (big) data processing. Recent efforts have focused on developing specific routing protocols for VANET networks in order to share and use information available in vehicles, such as position and dynamics.

However, due to the high mobility of nodes in a VANET environment, some protocols were tailored to addapt to specific applications, such as collision warning or cooperative driving. As the vehicles tend to move in platoons, concrete VANET networks are made up of groups of vehicles. Among the first applications of VANET were those to support road safety (e.g., collision warning/avoiding, cooperative driving - for fuel savings etc.) (José María de Fuentes, 2011). Other applications are pointing towards a better usage of road infrastructure, reducing traffic congestions and offering faster and safer routes for drivers. Typical support applications for road safety may be grouped into three main categories: i) driving assistance (navigation, cooperative collision avoidance, lane change assistance), ii) information provision (e.g., on speed limits) and iii) warning (on potential accidents, on obstacles on the road or providing warnings on traffic conditions) (Xiaodong Lin, 2008). All the above imply direct communication between vehicles, allowing for rapid information transmission, with as few delays as possible.

2. Related work

In (Blum, 2004), the authors describe an architectural model of security for VANET designed to counter the so-called "intelligent collisions" (i.e. collisions between messages that were caused intentionally). This is a type of attack, but building a robust architecture requires to envisage measures against possible attacks. The authors also propose using PKI (Public Key Infrastructure). Gerlach, (M. Gerlach, 2005) illustrates security concepts for automotive networks. Hubaux (Y.- C. Hu, 2003) looks on security from another perspective and focuses more on concepts of privacy and secure positioning. He points to the importance of a compromise between accountability and privacy and introduces the notion of Electronic License Plates (ELP), meaning the usage of single electronic vehicle numbers. Parno and Perig in (Perrig, 2005) explain some of the attacks that may occur in VANET sites. El Zarki (Stefan Saroiu, 2009) describes the specific infrastructure for VANET sites and briefly mentions some security issues and possible solutions.

The employment of digital signatures is discussed in (Meinel, 2002). The systems responsible for transportation and generation of data before it is transmitted may present physical security issues in a VANET environment.

[1] Corresponding author: marius.minea@upb.ro

Given the important benefits brought by intercommunication between vehicles and the existence of a large number of vehicles worldwide (around several hundred millions), it is obvious that this type of communication will become extremely popular. Security is one of the challenges that arise in these circumstances; for example, it is essential that information of utmost importance cannot be inserted or modified by an attacker; the system also should be able to determine the degree of responsibility of drivers, and at the same time, to protect the identity of possible drivers and passengers (Ram Shringar Raw, 2013). Although these problems seem similar to those encountered in other types of communication networks, they imply features that make them unique. Thus network size, vehicle speed, relevance of geographical location, sporadic connectivity between vehicles makes security in VANET networks a challenge that needs robust solutions. Vehicles are the interconected nodes in a VANET, provided they are equipped with specific onboard units (OBUs). Vehicles may be private (owned by individuals or companies) or public (e.g., means of transport, police cars, fire trucks etc.). The OBUs may belong to the government or a private sector provider. Considering that most VANET nodes consists of moving vehicles, network dynamics is characterized by high mobility and sporadic connectivity. Unlike traditional ad-hoc networks, in VANET the vehicles provide a large amount of traffic information, with significant bandwidth consumption. The size of VANET networks (M. Gerlach, 2005) is another feature to be taken into account. However, communication will take place locally, thus partitioning the network and making it scalable.

3. Study area and data collection

One of the most common types of charts is aimed at traffic characteristics during a peak period, limited from 60 to 90 minutes.

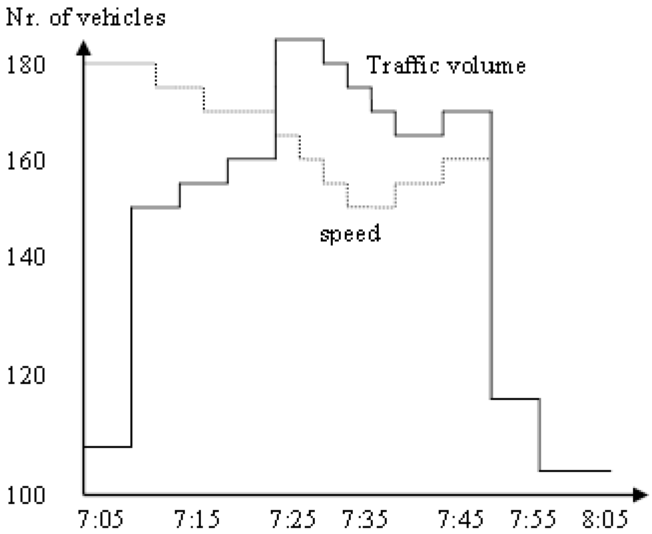


Fig. 1.
Traffic volume and speed variation in a 60 minute time slot located during peak traffic conditions

An inverse correlation between the speed and volume of traffic at speeds over 50 km / h, is generally observed. This is explained by the increased distance between vehicles on call duration due to increase response time due in particular to one of its components, the effective deceleration. Simultaneous growth on very small intervals of time, speed and traffic volume is explained by the existence of a relatively empty road that allows temporary occupation proportionality between these two factors. In current practice it often appears to flow studies the need to assess, on a scientific basis, the number of vehicles arriving in a particular area, at an intersection or into a parking lot. Subordinated to a certain frequency of unforeseen conditions, the number of vehicles arriving at a certain point in a given time, adheres to a Poisson distribution:

- each driver handles the vehicle independently of other vehicles;
- the number of vehicles that reach a certain point in a certain amount of time, is independent from the the number of vehicles passing at any other time intervals.

Distribution that meets these conditions is of a type:

$$P\ (n,q,T) = \frac{(qT)^n \exp(-q \cdot T)}{n!} \tag{1}$$

where: P (n, q, R) is the probability of n arrivals in T seconds, the value of q is the vehicle per second flow;
The working system using the Poisson relationship enables the development of charts for each value $q \cdot T$, representing the average flow, which have in abscissa different values of n (the number of incoming vehicles) and the probability

value P.

4. Proposed Model

Until now, studies on the VANET networks have focused on methods of communication based on the IEEE 802.11p, which forms the WAVE standard. IEEE 802.11p provides data rates ranging from 6 Mbps to 27 Mbps radio transmission over short distances, around 300 m (N. Wisitpongphan F. B., 2007).
Recently, the use of cellular technologies represents an alternative to IEEE 802.11p based on VANET. An important role is standardizing the most advanced broadcast / multicast services. The use of the third generation mobile communications system, called Universal Mobile Communication System (UMTS), has been used in the draft cooperation Cars (Car Co) (Project Cooperative Cars)

Table 1
Illustrates update rate, the minimum distance and maximum delay of messages according to the nature of services

Service	Maximum distance	Maximum delay	Update rate
Safety Recall Notice	400m	5s	-
Vehicle Diagnostics	500m	5s	10Hz
Wrong Way Driver Warning	500m	1s	10Hz
Emergency Vehicle Signal Preemption	1000m	1s	1Hz
Approaching Emergency Vehicle Warning	1000m	1s	-

It can be seen that the warning message for emergency traffic can be delivered in less than a second.
GSM / UMTS - is an international standard for private mobile communications. UMTS enables multi-media mobile communication and data at currently sufficient speeds, representing a good solution for UTC / PTM systems and transport equipment. Currently, UMTS networks can offer "personal navigation". The network service provider is able to precisely locate and provide UMTS terminal location selected services - such as for example the route to the nearest parking lot, gas station etc. Essentially, services are provided by the core network, a PABX digital type which provides data packet switching between different destinations.
Long Term Evolution (LTE) succeeds to increase the speed and capacity of mobile networks so that downlink speed can reach up to 100 Mbps and the uplink up to 50 Mbps, this for a 20 MHz band. LTE technology is a step that precedes 3.5 G and LTE Advanced, the fourth generation of radio technologies (4G). LTE objectives envisaged were: transfer speed, transfer and latency greatly enhanced emphasis on simplicity, flexibility spectrum to which was added to the increased capacity and a lower cost per bit. LTE provides for down-link rates of 300 Mbps, and the maximum up-link rate of 75 Mbps, the latency of less than 5 ms (Noha M. Sadek, 2015)

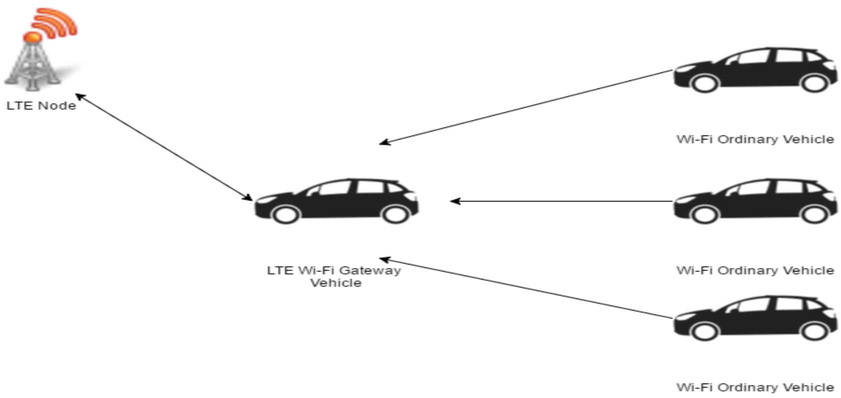


Fig. 2.
VANET-LTE network architecture

GPRS introduces transport services Packet Switched flow rates from 14 kbps to 170 kbps maximum. Basically GPRS is a standalone packet switching network plus the GSM network. GPRS interoperates with the GSM infrastructure at BSS subsystem level base stations and database from the NSS network subsystem (HLR, VLR, AUC). GPRS collects traffic data and GSM voice traffic remains switched by MSC. The data is transmitted via GPRS in fixed-length packets. Each packet contains the destination address in order to be routed to GPRS nodes. Changing the radio interface is given by the introduction of adaptive channel coding. This means that the protection of data varies in time, depending on the state of the radio channel. To a first approximation, the flow of a packet data system using error detection and retransmission is:

$$Throughput = (1 - BLER) * code\_data\_rate \text{ [b/s]} \quad (2)$$

Where BLER is the block error rate and code_data_rate is raw data rate in b / s for the physical channel. However, equation (1) does not take into account complex control procedures and error correction taking place in the RLC / MAC fields (Radio Link Control / Media Access Control) layer of the GPRS air interface (Noha M. Sadek, 2015).
The analysis presented in this paper can be used to achieve rate adaptation algorithms. As in other data transmission systems, the most important variables influencing the choice of coding scheme is measured channel quality of transport-interference ratio (C/I). In addition to the C/I channel, the size of the packet and channel fading characteristics play important roles in the coding scheme selection.
System flow is defined as the amount of data transferred over a period of time t, when t tends to infinity (Noha M. Sadek, 2015), (Konstantinos, 2011) (GHEORGHIU Razvan Andrei, 2015).

$$\mathrm{E[throughput]} = \lim_{t \to \infty} \frac{\mathrm{N(t)} \times \mathrm{packet\_length}}{\mathrm{t}} \; (\mathrm{kb/s}) \quad (3)$$

Where N (t) is the number of packets transmitted in the system, and packet_length is the length of the packet.
The number of packets N (t), divided by the time t is equal to the inverse of the predicted service packages, as t approaches infinity. To calculate the packet transmission delay, total delay segment can be divided into several components from channel assignment to the final confirmation (Noha M. Sadek, 2015):

$$T = T_{assig} + T_{tx} + T_{error\_correction} + T_{final\_acks} \quad (4)$$

Where T_{assig} is the length of time for the assigning procedure channel transmission and processing, TTX is the time of transmission, Terror_ correction is time error correction including retransmission T_{final_ack} is the last ACK (Acknowledgement) and ACK control and processing message transmission time (Konstantinos, 2011) .

Table 2
SNR values

SNR value [dB]	**Signal strength**
> 40	Excellent
25 - 40	Very good
15 - 25	Good
10 - 15	Low
5 - 10	Very low

For this study, 3 major intersections from Bucharest where chosen to simulate the A-VANET algorithm message distribution (Fig.3). The lane distribution was simulated using Synchro 8. In this way, we highlighted the number of lanes in this 1987 m (approx. 2 km) road section.
From left to right, these 3 intersections are highlighted with a specific set of values. These values represent the number of vehicles that cross this specific road segment in 1 hour, on each lane, and on every travel direction. The selected time slot (7:05-8:05) is considered a peak hour, when the morning commute takes place, from the west side of the city to the east side.

Fig. 3a.
Lujerului intersection

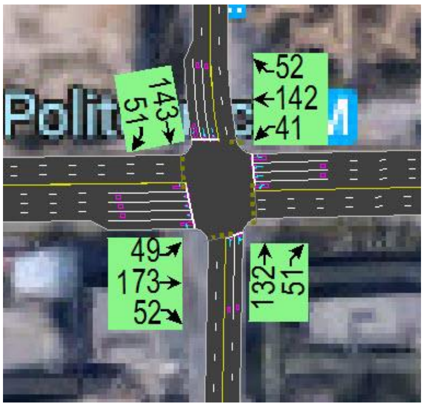


Fig. 3b.
Apaca intersection

Fig. 3c.
Leu Square intersection

The Poisson distribution is commonly used to determine the probable number of vehicles in a guided intersection, presuming the number of vehicles using the left relationship to be stored during a traffic lights operation cycle or knowledge of the number of vehicles arriving within time in a parking area at peak traffic circulation. In the measurements performed in the considered intersections a speed variation depending on traffic density is observed. If the density increases, interference phenomena occur between vehicles and the speed decreases until there are approximately 100 vehicles per kilometer of road or 1 vehicle to 10 meters.

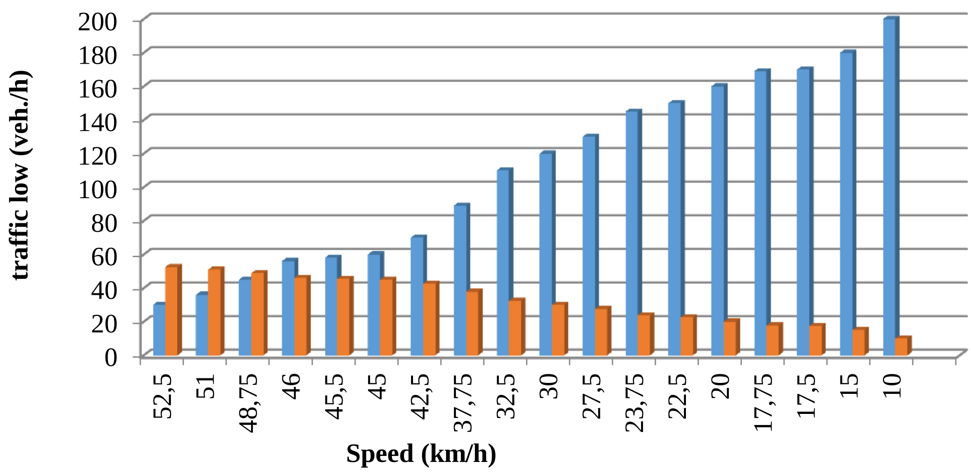


Fig. 4.
Traffic volume and speed variation

In the study conducted, the level of service for each intersection throughput depending on the average speed in a 24-hour period was revealed (Figure 6). The LOS are shown after a color code presented in Table 6. As it can be seen, urban congestion is evidenced by a maximum average speed of 40 km/h, restricted to the lower level B, and a minimum value of 7 km / h, enclosed at level F.
Peak times can be seen, where traffic congestion is present. Large timeframes for crossing the 3 intersections and therefore a much slower travel time of the road section are highlighted. Thus, a chart which shows the necessary travel time to cross the length of the road sector in a 24 hour period is shown (Fig. 7).The morning and afternoon commutes are revealed.

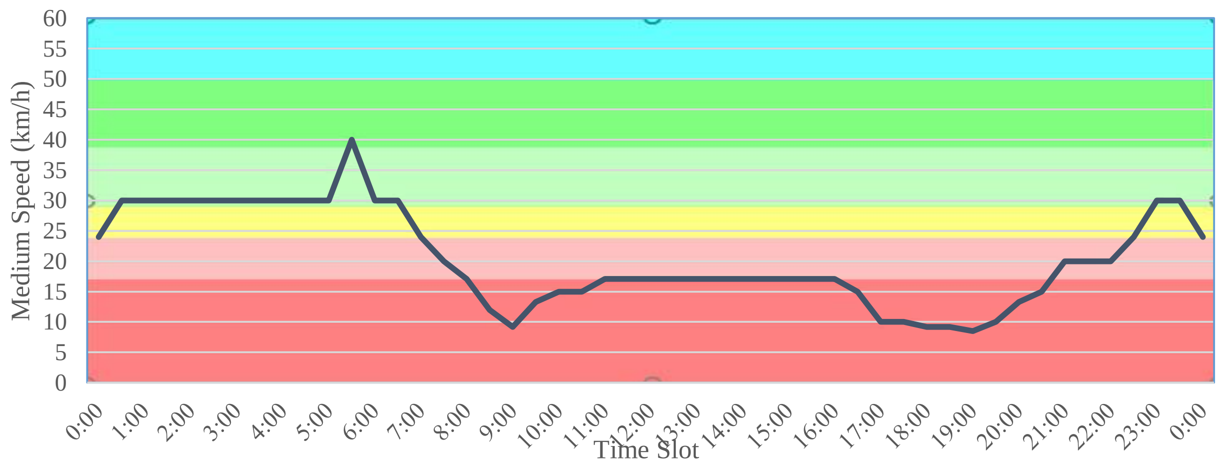


Fig. 5.
Variatia vitezei medie de circulatie in 24 ore cu evidentierea nivelurilor de serviciu

Table 3
Legend LOS

F	E	D	C	B	A
17-1km/h	22-17km/h	28-22km/h	39-28km/h	50-39km/h	>50km/h

Source (Das A. K., 2014)

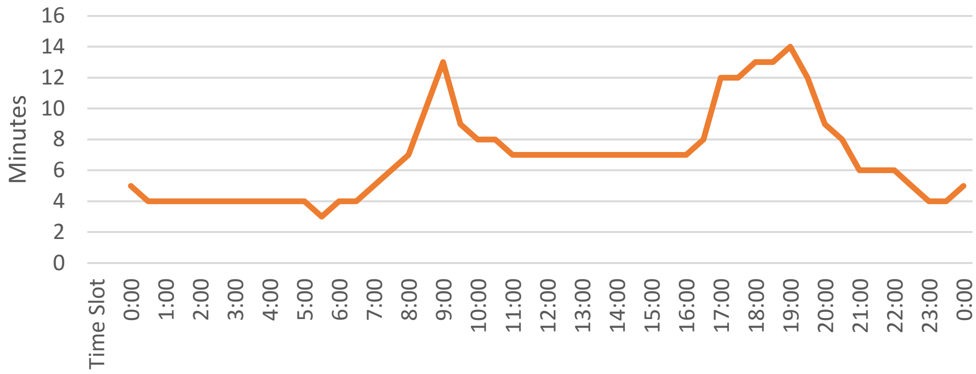


Fig. 7.
Travel time to cross the length of the road sector in a 24 hour period

If the number of vehicles per hour increases over 1400, but due to a traffic jam caused by a single damaged car or a parked car, quite often the case in urban transport, the vehicle row road speed drops drasticly . Especially during peak hours changes are made quite suddenly within relatively short time slots, within even a minute .
The present paper proposes a new model for a message sent over V2X (V2V, V2I) networks. The mode of transmission has been conceived in a secure manner. A roadside unit (RSU) issues a unique key, which is determined by its geographical position. When a node (vehicle) travels through the operating range of the RSU, a message containing a query field (ID area) will be sent to the RSU (table 3).

Table 4
The message structure

ID user	**ID area**	**Timestamp**	**Sensor data**

- ***ID user*** – identifies a user - for example, a vehicle (4 bytes);
- ***ID area*** – identifies geographic area based on GPS coordinates (6 bytes = 3 bytes alt. + 3 bytes long.).
- ***Timestamp* –** Represents the time at which the sensor reading was retrieved. To ensure time synchronization between different devices, the time is set to the existing ITS infrastructure for data coming in block (8 bytes).
- ***Sensor data* –** represents any kind of measurements performed on any sensors from the road infrastructure (1…n bytes).

The simplicity of this format allows for data storage over most types of databases. The message structure can be improved, depending on the chosen protocol, by adding predefined fields: number of packets sent, number of packets received, number of unsent packets and the residual capacity of the channel for ISM band (table 4) (A.J. Ghandour, 2013), (S. Ibrahim, 2015).

Table 5
Time and packet components

Timestamp	**TTL**	TX_r^c	RX_r^c	TNX_r^c	C_r

Where Timestamp – 8 bytes; TTL – 10 bytes; TX_r^c – 10 bytes; RX_r^c – 10 bytes; TNX_r^c – 10 bytes; C_r - 8bytes*nr.Selected channels.
Nr. of total transmitted packets (A.J. Ghandour, 2013):
$TX_r^c = \sum_{i=1}^{N} tx_{r,i}$ (4)
Nr. total received packets (A.J. Ghandour, 2013):
$RX_r^c = \sum_{i=1}^{N} rx_{r,i}$ (5)
Nr. of total unsent packets (A.J. Ghandour, 2013):
$TNX_r^c = \sum_{i=1}^{N} tnx_{r,i}$ (6)
The channels residual capacity or ISM band (A.J. Ghandour, 2013):
$C_r = C \cdot (1 - \omega_r)$ (7)
where ω_r - workload for channel from the ISM band

Confidentiality and data integrity is ensured by secured connecting devices used in the communication between users. In order to provide access control to the database to reach the information of interest, the user must authenticate as showed in Figure 1. Availability is ensured by creating authentication keys for each user, accessible at any authorized manner. The authenticity of the transmitted information is determined by the presence, or absence of authorized signatures. The scheme shall meet the following criteria:

1. The receiver shall verify the identity the transmitter claims to have;
2. The transmitter shall not deny that it is the author of the message;
3. The message shall not be prepared by the receiver.

Next, a final form of the message structure, depending on the communication protocol, is reached. In order to avoid saturation of an AP with authentication messages and information exchange, a TTL (Time To Live information) is included in the message structure. It represents a mechanism that limits the lifespan of the message, until it is received and aproved. When a RSU (source) or vehicle (source) identifies more callers in the vehicular network, it will redirect them to the closest neighbors, depending on the type of message (emergency cooperative, multimedia) (Fig.3). The final message structure is presented below table 6 (A.J. Ghandour, 2013), (S. Ibrahim, 2015):

Table 6
Message structure

Communication Protocol	**Message Type**		**Message Certificate**		**Digital Signature**
Timestamp	TTL	TX_r^c	RX_r^c	TNX_r^c	C_r

Where Communication Protocol – 1 byte; Message Type – 1 byte; Message Certificate – 125 bytes; Digital Signature – 56 bytes; Timestamp -8 bytes; TTL – 10 bytes; TX_r^c – 10 bytes; RX_r^c – 10 bytes; TNX_r^c – 10 bytes; C_r - 8bytes*nr.Selected channels.

The currently presented algorithms focuses on the idea that information is transmitted between cluster or groups of vehicles, rather than individual vehicles. In each group, one or more vehicles, chosen based on their positioning will transmit data to their neighbors (who are still groups). A defining criterion in forming groups is geographical positioning. Thus, considering the information received from the GPS system and dividing the area into cells, a vehicle can determine whose group belongs to at time (area division in cells is predetermined in advance). Each vehicle processes all events locally, both those directly observed and those reported by other vehicles, before taking a decision on the event. In each group there are one or more leaders who distributes messages. One way to check the received data is to compare it to other received information from other sources about the event. Thus, to test the validity of messages, and that of the source, it is required that during the message routing, intermediate nodes must sign over the signature of the previous transmitter. A invalid signature at any time will invalidate the message reaching the final receiver.

The main aspects that underlie the exposed solution are: vehicle position when transmitting messages, the time at which the emission is happening and existing certification authorities in the area at the start of the transmission. If a validity request regarding a message that has reached a particular vehicle is processed, the next fields are checked: the message type and the attached digital signature. If the message has been validated by the RSU, it will return a response to the destination vehicle. If the signature is valid, the answer is positive; otherwise, the answer is negative (rejected).

To prevent an attack, this confirmation message contains a digital signature. If an attacker disrupts a message, the vehicle may notice this purpose, and then verification is performed with a public key emitted by the RSU, based on the received digital signature. (Fig.3). Certificates are temporally / spatially limited, which allow them to be used in a certain geographical area or in a pre-determined period of time. The basic idea is that if a user wishes to actively participate in a VANET network, he/she must make use of an area identification device in the OBU. Each device is an assigned identifier and a certificate. During initialization, the device will be recorded with the user's account; user information shall be maintained at the service provider and shall not be stored in the onboard unit. When a user enters a region and wants to use services from that area, he/she uses the earlier mentioned device. The request message will be encrypted using the providers' public key, thus obscuring the device's identity for occasional "unauthorized listeners". Users get a certificate only when they need a service. The certificate revocation is done automatically when the message lifetime expires or when they exit the zone borders. For each new certificate the service provider checks if the previous certificate has been revoked. If so, the new certificate may be issued.

Due to the dynamic property of VANET networks, message queues can form. For example, signing messages is via the access point in close proximity, but when the vehicles travel at a high speed or change their route, the signed message will not be able to get back to the vehicle which issued it because it emerged from the coverage of the access point. However, the message will be sent, so it will be stored in a message queue, and will subsequently be sent when the vehicle that issued it is in the coverage of another secure access point. The message routing can be done in two ways:

- directly, in case the destination is within range of the source;
- through intermediate nodes (vehicles), if the destination is not in the source coverage area.

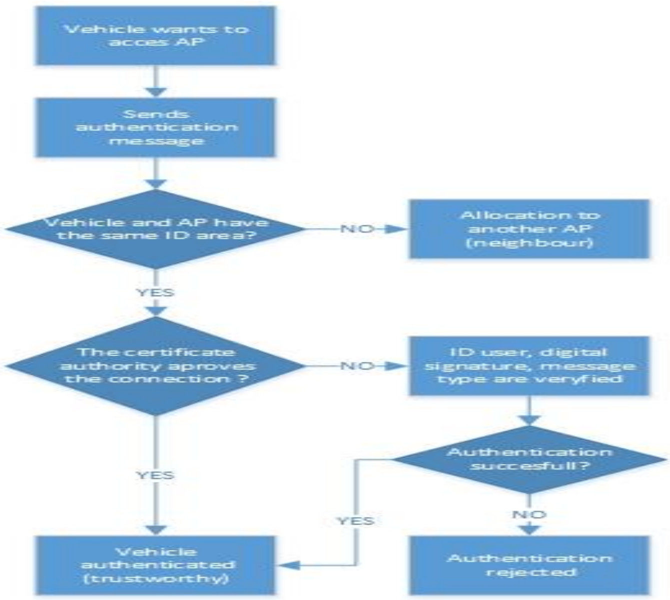


Fig. 6.
Vehicle authentication flow

5. Conclusion

The study focuses on the idea that information is transmitted between groups rather than between individual vehicles. In each group, one or more vehicles, selected on the basis of their positioning will transmit data to their neighbors (who are all groups). A defining criterion in forming groups is geographical position. Thus, considering the information from the GPS system and dividing the area into cells, a vehicle can determine the group that belongs to at a certain time (dividing cells is a predetermined area in advance). Each vehicle processes local events, both those directly observed and those reported by other vehicles, before taking a decision on the event. In each group there are one or more leaders who distribute messages. One way to check the data received is a comparison to other information received from other sources about the event. Otherwise, to test the validity of messages and the source it is required that during the message routing, intermediate nodes signature to sign over the previous transmitter. A signature invalid at any time will invalidate the message reaching the final receiver. The main issues that underlie the solution presented are: the vehicle position when transmitting the messages, the time at which the emission is happening and existing certification authorities in the area at the start of transmission.

Compared to a simple unsecured message transmission (section 4, tables 4 and 5), the proposed solution (section 4, Table 6) will require an additional network load. The additional amount of data introduced by the proposed security algorithm is due to added digital signatures and counting received and undelivered messages. The secure transmission of messages between vehicles in traffic is made depending on whether an entity for certification is present in the area, and depends on distance between vehicles which want to communicate, if the destination node is within the transmission range; otherwise, there is need to select a route that includes several hops in the transmission of messages (Section 4, Fig.3).

The next steps will be to implement the algorithm and to test it in a simulated, or experimental environment, in order to determine the quality of service parameters in the newly, more secure format. This will ensure the algorithm does not affect messages that need rapid delivery to destination.

References

Alexandrescu, R.V.; Surugiu, M.C.; Petrescu, I. 2015. Study on the implementation of protocols for providing security in average VANET intervehiculary network communication systems”. In *Proceedings of the 2015 7th international conference on eleconics,computers and artificial intelligence (ECAI)*, WW1-WW6 p., Bucharest.

Blum, A. 2004. The Threat of Intelligent Collisions, *IT Professional*, 24-29.

Das, A.K.; B.P. 2014. Level of Service criteria of urban streets using Clustering Large Application (CLARA), *Advances in Transportation Studies an international Journal Section B*, 32: 75-88.

Gerlach, M.V. 2007. (V2VCOM) An Approach to VANET Security.

Ghandour, A.J. et al. 2013. Improving Vehicular Safety Message Delivery through the Implementation of a Cognitive Vehicular Network.

Hu, Y.- C.A.P. 2003. Packet Leashes: A Defense Against Wormhole Attack in Wireless Networks, *Infocom IEEE*.

Ibrahim, S.M.H. 2015. A Comparison on VANET Authentication Schemes: Public Key Vs. Symmetric Key. In *Proceedings 2015 Tenth International Conference on Computer Engineering and Systems (ICCES),* 341-345.

José María de Fuentes, A.I.-T. 2011. Overview of Security Issues in Vehicular Ad-hoc Networks, Handbook of Research on Mobility and Computing: Evolving Technologies and Ubiquitous Impacts.

Konstantinos, T. 2011. Modeling and Evaluation of LTE in Intelligent Transportation Systems. University of Twente, 105 p.

Meinel, L.G. 2002. Digital Signatures for Automobiles. In *Proceedings of Systemics, Cybernetics and Informatics* (SCI).

Perrig, B.P. 2005. Challenges in Securing Vehicular Networks. In *Proceedings of the Workshop on Hot Topics in Networks* (Hot Nets-IV).

Project Cooperative Cars, C. (n.d.). Available from Internet: <http://www.aktiv-online.org/english/aktiv-cocar.html/>.

Ram Shringar Raw, M.K. 2013. Security Challenges, Issues and their Solutions for VANET, *International Journal of Network Security & ITS Applications* (IJNSA), 95-105.

Stefan Saroiu, A.W. 2009. Enabling New Mobile Applications with Location Proofs. In *Proceedings of the 10th workshop on Mobile Computing Systems and Applications.* California.

Wisitpongphan, N.F.B. 2007. Routing in sparse vehicular ad hoc wireless networks, *Selected Areas in Communications, IEEE Journal*, 1538-1556.

Wisitpongphan, N.O.T. 2007. Broadcast storm mitigation techniques in vehicular ad hoc networks, *Wireless Communications, IEEE*, 84-94.

Xiaodong Lin, et al. 2008. Security in Vehicular Ad-hoc networks, *IEEE Communications Magazine*, 88-95.

BIOMETRIC IDENTIFICATION SYSTEMS IN FUNCTION OF TRANSPORT SAFETY BY APPLYING CVQ COMPRESSION METHOD

Mirko Čorić[1], Anita Gudelj[2], Tomislav Bubalo[3]
[1,2] University of Split, Faculty of Maritime Studies, Ruđera Boškovića 37, 21000 Split, Croatia
[3] University of Zagreb, Faculty of Transport and Traffic Sciences, Vukelićeva 4, 10000 Zagreb, Croatia

Abstract: Generally, fingerprint, face and iris recognition occupy a large place in biometric identification, and they are among the most popular biometric methods. Popularity of biometric identification is growing in all areas of transport, such as maritime, air and road transport. All these biometric methods operate following the same principle: creation of unique digital templates that are extracted from data such as iris, face and fingerprint images. Specially designed algorithms are used for creation of unique digital templates. Future tendencies and politics suggest usage of real fingerprint, face and iris images instead of templates. Biometric identification systems in transport often require storage and transmission of images, and therefore images should be compressed in order to save resources. This paper explores and analyses effects of Classified Vector Quantization (CVQ) compression method against fingerprint, iris and face images. Grayscale images from public databases are used in the experiment. Results show that CVQ is not equally effective against all three types of images at the same bit rate level because some types have different image properties in terms of image edges and abrupt transitions between pixel values. Advantages over ordinary Vector Quantization (VQ) are pointed as well.

Keywords: biometrics, identification, CVQ, compression, transport, safety.

1. Introduction

Biometric identification is used in security and access control applications in order to identify persons based on their physical characteristics that can be checked on automated basis. Biometric identification technologies occupy larger and larger place in many areas of transport and traffic security lately, especially since the 9/11 event (Amoore, 2006; Wikipedia, 2016). Fingerprint, face and iris recognition are considered to be among the most widespread and most studied biometric modalities (Woodward et al., 2003; Daugman, 2004; Biometrics.gov, 2016; Bača et al., 2012). Biometric technologies are being adopted in different areas of transport constantly. Governments and international organizations are focused on evaluation of the transportation related security risks. Many of these initiatives require integration of biometrics to authenticate the identities of individuals with access to critical cargo, secure areas of transportation facilities, different traffic areas and associated information technology systems. For example, The Tocumen International Airport in Panama operates an airport-wide surveillance system using hundreds of live facial recognition cameras to identify wanted individuals passing through the airport (ihsairport360.com, 2014). Few years ago, Spanish has installed multi-biometric identification system in two of its largest airports to identify persons on the airport access-control kiosks (findbiometrics.com/spanish-airports-install-multi-biometric-security-systems/, 2010). Furthermore, Canadian National Railway (CNR), the fifth largest railroad in North America, is integrating fingerprint biometrics into its Speedgate control system which was designed to monitor commercial truck access to CNR's inter-modal transfer facilities located throughout North America (Bragdon, 2011). Another example is American Coast Guard which is using portable iris scanners in order to quickly identify smugglers or suspected migrants at sea (Securing our borders: Biometrics at sea. Coast Guard Compass, 2011). There are numerous other examples of the use of biometric identification in various transport areas. In fingerprint, face and iris identification systems (further in text referred just as biometric identification systems), large amounts of biometric data needs to be stored in databases, as well as often sent via different communication channels (e.g. Internet) in order to exchange data with other parts of the systems. Majority of existing biometric identification systems do not operate with real biometric data (real fingerprint, face and iris images), but instead use unique features that are extracted from real biometric data using specific algorithms. These unique features are often called digital templates or codes, and they uniquely represent each and every individual (Jain et al., 2007). Simpler and more desirable solution would be the use of real biometric data (real fingerprint, face and iris images) instead of digital templates since intermediate steps that include involvement of specific algorithms are avoided in that case. Moreover, different politics advocate for the use of real biometric data instead of digital templates in order to achieve interoperability and vendor neutrality (National Institute of Standards and Technology. U.S. Department of Commerce., 2013). Also, storage of extracted features (digital templates) is considered to be non-reversible biometric data, meaning that the original iris, fingerprint or face image cannot be restored from extracted features (Wayman et al., 2005). Because of these flaws using only digital templates on the one hand, and the fact that storage and transfer of real raw biometric data (fingerprint, face and iris images) consumes a lot resources on the other hand, a solution can be found in the use of real but compressed biometric data (compressed fingerprint, face and iris images). Experiments already showed that this solution is possible, and that recognition accuracy is not significantly affected (Funk et al., 2005; Daugman and Downing, 2008; Mascher-Kampfer et al., 2007). Previous studies showed that Vector Quantization (VQ) compression approach stands side by side with other standard techniques used for compression of biometric data images, and even outperforms them (Elad et al., 2007; Mascher-Kampfer et al., 2007; Kekre et al., 2010; Matschitsch et al., 2007). In this paper more advanced type of VQ is used

[1] Corresponding author: mcoric@pfst.hr

called Classified Vector Quantization (CVQ) where the classification of blocks of pixels (vectors) is based on edges (Ramamurthi and Gersho, 1986). Compared to ordinary VQ, CVQ is much faster in terms of coding time, which directly affects the overall recognition procedure (Čorić et al., 2016). If compared with each other, mentioned biometric data (iris, face and fingerprint images) are quite different in terms of image properties (different levels of transitions between neighbouring pixel values, different contrast levels, etc.). This work explores and analyses differences in image quality between iris, face and fingerprint images after being coded and compressed using CVQ . The paper is organized as follows. Next chapter briefly describes CVQ compression method, third chapter describes methodology and results, and the conclusion is given in the final chapter.

2. CVQ approach

Generally, VQ is a technique in which the block of pixels (vector) from the original image is replaced with the closest matching block of pixels (vector) from the codebook. In other words, approximation is done. It is not necessary to search the entire codebook to find the most similar approximation vector during VQ of the input vector. It is possible to select and consider only one subset of the codebook when choosing approximation vector. In other words, it is possible to classify the input vector, i.e. determine to which subset of the total codebook it belongs. Described method is called CVQ (Fig. 1).

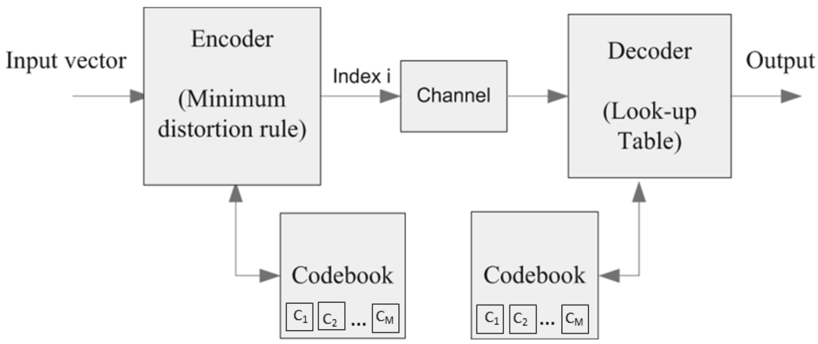


Fig. 1.
CVQ general description
Source: (Ramamurthi and Gersho, 1986)

In CVQ index (address) of the vector from the codebook consists of two parts. The first part, generated by classificator, determines the codebook C_i in which the search for approximation vector is performed. The second part of the index is the address of the code vector within each codebook. Codebooks C_i are generated so that the overall training sequence T is divided into M subsequences $T_j(j=1,2,3,\ldots,M)$ after it passes through the classifier. Afterwards, every codebook L_j of size $m_j(j=1,2,3,\ldots,M)$ is generated using one of the algorithms (algorithms designed for development of codebooks) for the appropriate subsequence only. LBG algorithm (Linde et al., 1980) is used in this work. Overall codebook is composed from all codebooks L_j. Classification of vectors from original image can be performed based upon different image properties. In the case of image compression, classification based on edges is the most common. This work uses CVQ based on the method called comparison of locally thresholded image vectors with a predefined set of binary edge templates (Quweider and Salari, 1996).

3. Methodology and results

3.1. Basic idea

VQ essentially involves replacement of the original blocks of pixels (vectors) with the closest blocks of pixels (vectors) that are placed within a codebook/s. This is called approximation. Ordinary VQ treats equally all parts of the image, while CVQ pays special attention to the edges that are located within the image. It means that edges are approximated better than the rest of the image if CVQ is used. It is one of the most important feature of CVQ since edges within the image play the most important role for the human visual impression and resolution of details. Edges can be described as lines, curves and all the image parts where sudden transitions between neighbouring pixels occur. Average images from everyday environments do not have a tendency to contain as much edges as fingerprints and iris images do (dense network of lines and curves are present within these images). On the other hand, face images tend to be more similar to average images considering their properties and amount of edges. CVQ can take advantage of this feature (increased amount of edges within images) in order to achieve better results, especially for fingerprint and iris images. Generally, codebooks contain approximation vectors that are derived from training set of vectors extracted from training original images representing the environment with which images to be compressed are related. In the case of CVQ, training vectors are classified into different edge classes first (using method from Quweider and Salari, 1996 in this work), and the separate codebook is developed for each and every training set of vectors for each and every edge class. If there is a lack of edges within the training original images, then the lack of training vectors is present within training sets of vectors belonging to these edge classes. Furthermore, if there is a lack of training vectors within a training set of vectors, codebook derived from that set of training vectors is not good enough. This is not an issue in the case of mentioned biometric images since these images contain more edges than average images.

3.2. Methodology

The same procedure was performed for all three kinds of biometric data, meaning that there were 3 test cases (fingerprint, iris and face images test case). Gray fingerprint, iris and face images were taken from available public databases on internet (advancedsourcecode.com/fingerprintdatabase.asp, 2012; pics.psych.stir.ac.uk/, 2010; phoenix.inf.upol.cz/iris/, 2009). In the fingerprint test case, 22 fingerprint images of size 248x338 pixels were taken as a training images for extraction of training vectors of size 4x4 pixels, meaning that a total of 115 258 training vectors were extracted. Extracted training vectors were classified (distributed) among 30 different classes. 28 classes refer to different types of edges, one class (mixed class) refers to all edges that are not covered by these 28 classes, and one class refers to all the vectors that are not classified as edges. Afterwards, LBG algorithm was used in order to develop separate codebooks for each of these 30 classes. Codebooks of different sizes (4, 8, 16 and 32 codewords per class) were developed for each class, therefore input vectors from original fingerprint images can be coded at different bit rates (ranging from 0.43 - 0.625 bits per pixel) using CVQ. Finally, few randomly selected fingerprint images from database were coded (i.e. compressed) at mentioned bit rate levels. Mean Squared Error (MSE) (en.wikipedia.org/wiki/Mean_squared_error, 2014) was used as a measurement of quality of coding (i.e. compression). All the steps are performed using Matlab scripts designed for this purpose. Results are presented in the next subsection. As for the iris test case, the same methodology was applied over the iris images, provided that 6 iris images of size 640x480 pixels were taken as a training images in order to achieve approximately the same number of training vectors (115 200 training vectors) as in the fingerprint test case. Again, vectors extracted from these 6 training iris images were classified among 30 classes, separate codebooks were developed for each class, and a few randomly selected iris images were compressed using the same bit rate levels as in the fingerprint test case. And finally as for the face test case, the same procedure was applied again, provided that 11 face images of size 352x480 pixels were taken as a training images in order to achieve approximately the same number of training vectors (116 160 training vectors) as in the fingerprint and iris test case. Other steps are performed as in the previous two test cases. Results for the iris and face test case are presented in the next subsection as well. Fig. 2. shows samples of training images for all three test cases.

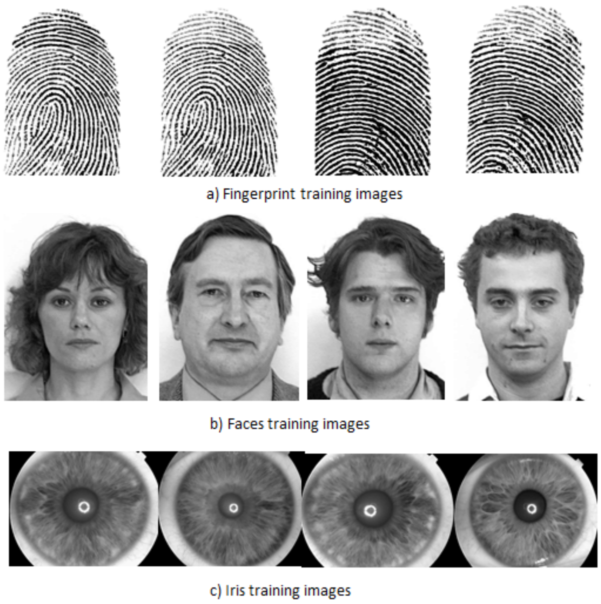


Fig. 2.
Samples of training images for each test case
Source: Public internet databases

3.3. Results

Statistics of extracted and classified vectors for all three test cases is shown in Table 1.

Table 1
Classified vectors statistic for each test case

Fingerprint test case			Iris test case		Face test case	
class	number of vectors	% of vectors	number of vectors	% of vectors	number of vectors	% of vectors
1	1406	1.23	259	0.22	209	0.18
2	3017	2.63	3146	2.73	2042	1.76
3	2392	2.09	3829	3.32	1718	1.48
4	1758	1.53	698	0.61	412	0.35
5	2983	2.60	4565	3.96	2903	2.50
6	3029	2.64	2458	2.13	1958	1.69
7	1478	1.29	211	0.18	252	0.22
8	3347	2.92	3318	2.88	2450	2.11
9	2833	2.47	3250	2.82	2362	2.03
10	1530	1.34	636	0.55	326	0.28
11	3293	2.87	4783	4.15	2731	2.35
12	3560	3.11	2391	2.08	2364	2.04
13	3854	3.36	361	0.31	63	0.05
14	800	0.70	226	0.20	85	0.07
15	1088	0.95	1478	1.28	526	0.45
16	16805	14.67	5352	4.65	1758	1.51
17	820	0.72	304	0.26	129	0.11
18	464	0.40	303	0.26	151	0.13
19	1067	0.93	1796	1.56	704	0.61
20	7564	6.60	3657	3.17	2142	1.84
21	3520	3.07	551	0.48	430	0.37
22	1828	1.60	1432	1.24	737	0.63
23	1560	1.36	1987	1.72	806	0.69
24	3094	2.70	1282	1.11	486	0.42
25	2900	2.53	1268	1.10	680	0.59
26	1543	1.35	2155	1.87	1277	1.10
27	1483	1.29	880	0.76	574	0.49
28	3258	2.84	504	0.44	409	0.35
mixed	8357	7.29	12171	10.57	9230	7.95
non-edge	23945	20.90	49949	43.36	76246	65.64

As it can be seen from the table, in the fingerprint test case 79.1 % of vectors are classified as edges, in the iris test case 56.64 %, while in the face test case 34.36 % of vectors are classified as edges. Since classes in the fingerprint test case contain more edge vectors then classes from the other two test cases, codebooks developed for the fingerprint test case contain better approximation vectors. Therefore, quality of compressed fingerprint images is better than the quality of compressed images from the other two test cases at the same bit rate levels. Several images per each test case are coded, and the average coding results for each test case are shown in Table 2.

Table 2
Average MSE for each test case

bpp	MSE for the fingerprint test case	MSE for the iris test case	MSE for the face test case
0.437	32.54	33.87	38.12
0.5	17.68	20.71	29.53
0.562	8.04	11.16	22.61
0.625	4.36	7.59	18.06

Results after compression show that iris images have reduced MSE compared to face images, and fingerprint images have reduced MSE compared to face and iris images. This means that compressed fingerprint images achieve better quality than other two types of images at the same bit rate levels. They are followed by iris images, while face images take last place in terms of image quality.

4. Conclusion

This paper examines the effect of CVQ compression method when applied over three different types of biometric data, namely fingerprint, iris and face images. In general, CVQ compression method takes advantage of large number of edges in order to enhance the quality of all the parts of the image containing the edges. Results show that among the mentioned biometric data, fingerprint images are the most suitable candidates for CVQ compression method since fingerprint images contain more edges (valleys and ridges within fingerprint images) than other two types of images. Different areas of transportation and traffic security can benefit from this research, especially ones that use fingerprint biometric systems. The value of this research increases even further due to the fact that multimodal biometric systems are the future, and that exactly fingerprint, iris and face biometric systems are the basis for the multimodal biometric systems.

References

Amoore, L. 2006. Biometric borders: Governing mobilities in the war on terror, *Political Geography*, 25(3): 336-351.

Bača, M. et al. 2012. Using biometric characteristics to increase ITS security, *PROMET-Traffic&Transportation*, 19(6): 353-359.

Bragdon, C. 2011. Transportation security. Butterworth-Heinemann. USA. 43 p.

Čorić, M. et al. 2016. Classified vector quantization and its application on compression of iris images in the safety of marine systems, *PROMET-Traffic&Transportation*, 28(2): 125-131.

Daugman, J. 2004. How iris recognition works, *IEEE Transactions on circuits and systems for video technology*, 14(1): 21-30.

Daugman, J.; Downing, C. 2008. Effect of severe image compression on iris recognition performance, *IEEE Transactions on Information Forensics and Security*, 3(1): 52-61.

Elad, M. et al. 2007. Low bit-rate compression of facial images, *IEEE Transactions on Image Processing*, 16(9): 2379-2383.

Federal government of the United States. 2011. The National Biometrics Challenge. Available from Internet: <http://www.biometrics.gov>.

Funk, W. et al. 2005. Evaluation of image compression algorithms for fingerprint and face recognition systems. In *Proceedings from the Sixth Annual IEEE SMC Information Assurance Workshop,* 51-59.

Indra. 2010. Spanish Airports Install Multi-biometric Security Systems. Available from Internet: <http://findbiometrics.com/spanish-airports-install-multi-biometric-security-systems/>.

Jain, A.K. et al. 2007. *Handbook of biometrics*. Springer Science & Business Media. USA. 4 p.

Kekre, H.B. et al. 2010. Performance Comparison of DCT and VQ Based Techniques for Iris Recognition, *Journal Of Electronic Science And Technology*, 8(3): 223-229.

Linde, Y. et al. 1980. An algorithm for vector quantizer design, *IEEE Transactions on Communications*, 28(1): 84-95.

Mascher-Kampfer, A. et al. 2007. Comparison of compression algorithms' impact on fingerprint and face recognition accuracy, *Visual Communications and Image Processing*, 6508: 1-10.

Matschitsch, S. et al. 2007. Comparison of compression algorithms' impact on iris recognition accuracy. In *Proceedings from the International Conference on Biometrics*, 232-241.

National Institute of Standards and Technology. U.S. Department of Commerce. 2013. Latent Interoperability Transmission Specification. New York: NIST Special Publication 1152, 46 p.

Palacký University. 2009. Phoenix iris database. Available from Internet: <http://phoenix.inf.upol.cz/iris/>.

Psychology, School of Natural Sciences, University of Stirling. 2010. 2D face sets. Available from Internet: <http://pics.psych.stir.ac.uk/>.

Quweider, M.K.; Salari, E. 1996. Efficient classification and codebook design for CVQ. In *IEE-Proceedings-Vision, Image and Signal Processing*, 344-352.

Ramamurthi, B.; Gersho, A. 1986. Classified vector quantization of images, *IEEE Transactions on Communications*, 34(11): 1105-1115.

Rosa, L. 2012. UPEK Fingerprint Database. Available from Internet: <http://www.advancedsourcecode.com/fingerprintdatabase.asp>.

Stephanie Young, L.T. 2011. *Securing our borders: Biometrics at sea. Coast Guard Compass*. [Blog] Official blog of the U.S. Coast Guard. Available from Internet: <http://coastguard.dodlive.mil/2011/11/securing-our-borders-biometrics-at-sea/>. [Accessed 09 Aug. 2016].

Vogel, B. 2014. .Panama puts names to more faces. Available from Internet: <www.ihsairport360.com>.

Wayman, J. et al. 2005. *An introduction to biometric authentication systems*. Springer London. UK. 10 p.

Wikipedia. 2014. Mean squared error. Available from Internet: <https://en.wikipedia.org/wiki/Mean_squared_error>.

Wikipedia. 2016. Biometrics. Available from Internet: <https://en.wikipedia.org/w/index.php?title=Biometrics&oldid=737721127>.

Woodward, J. et al. 2003. *Biometrics:[identity assurance in the information age]*. McGraw-Hill/Osborne. USA. 21 p.

EA SEA-WAY DATABASE TOOL FOR ASSESSMENT OF INTEGRATION OF THE ADRIATIC PORT SYSTEM WITH THE HINTERLAND

Azra Ferizović[1], Elen Twrdy[2], Olja Čokorilo[3], Alem Čolaković[4], Marina Zanne[5]
[1,4] University of Sarajevo, Faculty of Traffic and Communications, Sarajevo, Bosnia & Herzegovina
[2,5] University of Ljubljana, Faculty of Maritime Studies and Transport, Ljubljana, Slovenia
[3] University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia

Abstract: The Adriatic-Ionian macro region is one of the four Mediterranean sub-regions, recorded approximately 5.2 million of cruise passengers and 17 million ferry passengers in 2013. The study performed within the WP4 of EA SEA-WAY project covered twenty ports in six countries of the Adriatic-Ionian region and their hinterland connections assessment. The primary objective of each database is to enable a comprehensive view of data making it easier to focus on analysis. Database should have functionalities such as systematization, timelines collection and data entry into one place by using user friendly interface. For developing big databases, such as database for EA SEA-WAY project, there is a need for making a model to provide the integrity and interconnectedness data. Relational databases have dominated the software industry for a long and ERD (*Entity-Relationship Diagram*) and it is used to visually represents the relationship between database entities. Also, it is very important to decide which DBMS (*Database Management System*) to use in creating database. In this paper is presented a solution for EA SEA-WAY project database as a useful assessment tool for the ports and other stakeholders in the Adriatic-Ionian macro region.

Keywords: EA SEA-WAY, database, assessment, port, hinterland.

1. Introduction

EA SEA-WAY (European Adriatic Sea-Way) is the project co-funded by the European Union, Instrument for Pre-Accession Assistance. The general objective of EA Sea-Way Project is to improve the accessibility and the mobility of passengers across the Adriatic area and its hinterland. This improvement should be done through the development of new cross border, sustainable and integrated transport services and the improvement of physical infrastructures related to those new services. One of main challenges was to explore a better integration of urban and regional connections between ports, airports and main tourist destinations/urban areas. According to this several studies have been done.
Most experts and project partners spend the majority of their time searching relevant data and the hardest part of delivering studies was lack of information. It is the reason why project team prepared and delivered different kind of databases according to the different results to be reached through work packages. The main goal of EA-SEA Way database is to enable more comprehensive view of data related to the project activities. There is a need for easy manipulating of data and storing them into one place. That will enable quick processing and analyzing data.

2. EA SEA-WAY Project

2.1. Objectives of the EA SEA-WAY Project

The general objective of European Adriatic Sea-Way (acronym EA Sea-Way) is to improve the accessibility and the mobility of passengers across the Adriatic area and its hinterland, through the development of new cross border(CB), sustainable and integrated transport services and the improvement of physical infrastructures related to those new services (EA Sea-Way, 2016). The EA SEA-WAY consists of six Work Packages (WPs) and main objective of WP4 is assessment of the Adriatic port system and its integration with hinterland.
The EA SEA WAY project is a part of the IPA Adriatic Cross Border Cooperation Programme 2007-2013 co-financed by the European Union. The general objective of the project was to improve the accessibility and the mobility of passengers across the Adriatic area and its hinterland, through the development of new cross - border, sustainable and integrated transport services and the improvement of physical infrastructures related to those services.
The project was divided into 6 work packages which have involved:

- 20 partners,
- 16 associates,
- 8 countries (Adriatic-Ionian region).

2.2. Assessment of the passengers traffic flows in the Adriatic-Ionian area

The fourth work package (WP4) foresees the assessment of the Adriatic port system and its integration with hinterland, based on data collected on the applicable legal acts, studies, analyses and implemented projects (WP4, 2015). The study performed within the WP4 covered twenty ports in six countries of the Adriatic-Ionian region.

1 Corresponding author: azra.ferizovic@zfbh.ba

Fig. 1.
Adriatic-Ionian ports as a scope og WP4 research

The Adriatic–Ionian region in 2013 the region recorded approximately 5.2 million passengers and 17 million of cruise and ferry passengers, respectively (Čokorilo et al., 2015). The Fig.2 presents the current situation of Adriatic-Ionian port system integration with hinterland regarding the different modes of transport infrastructure.

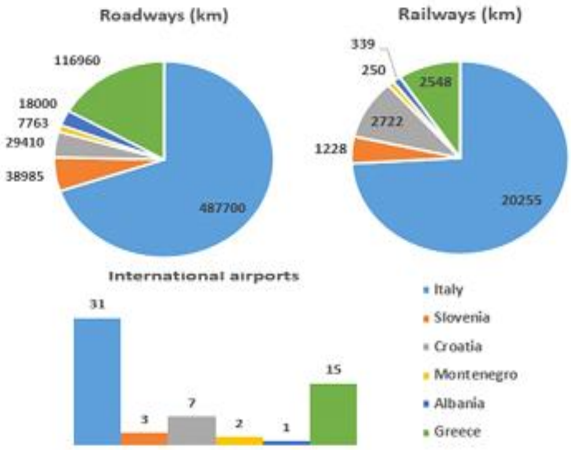


Fig. 2.
Adriatic-Ionian port system integration with hinterland

There was a significant gap in the density and degree of development of inland infrastructure in the countries of the Adriatic – Ionian region. In particular, the poor state of infrastructure, and hence the low quality of transport services, is characteristic for the Western Balkans countries.
Ports cannot expect significant progress in the future without good hinterland infrastructure. Rail and air transport represents a great opportunity for the seaport competitiveness and can considerably improve mobility within ports and their hinterland area.

3. EA SEA WAY Database

3.1. EA SEA-WAY Database functionalities

Development of database was one of challenges in order to do analyse of passengers behaviour and maritime traffic flows in the Adriatic basin. Developed database had great role to create scenarios linked to the development of: passenger traffic, transport modal choices, physical infrastructures and services.
Database is a software structure intended for storing, analyzing and searching a group of related and associated data. The easiest and fastest way of developing EA SEA-WAY database was to use Microsoft Access while this DBMS (Database Management System) allows to create user friendly interface through different forms for inserting and searching data as well as different reports for a comprehensive view of data. Microsoft Access enables easier database design, implementation, management and use. Microsoft Access 2016 provides a rich platform for developing database management solutions with easy-to-use customization tools (Microsoft, 2016). Also, due to some other technical features and benefits it was used this DBMS and version 2007 was selected due the widespread usage of this version. Developed database is desktop based version that allows flexibility for each user to perform the necessary changes and adapts to the database to specific needs.
EA SEA-WAY database provide the following basic functions:

- Data sorting in the corresponding tables and the corresponding data types,

- Creating a user friendly interface for easy manipulation of data,
- Enabled different reports that allow review of the data in summary form,
- Enabled to search data according to different criteria,
- Enabled options for printing data directly from the database,
- Enabled to converting reports in different formats, for example *.pdf.

EA SEA-WAY database facilitate development of studies and assessment of integration of the Adriatic port system with the hinterland**.** That could help improvement of Adriatic port system, its integration with hinterland and strengthening of intra-Adriatic connections.

3.2. Database model

EA SEA-WAY database consists many different data types. Many experts from different expertise fields included in making concept of database (Database Software and Applications 2016). Database consists indicators on passengers' behaviour and maritime traffic flows in Adriatic basin, current traffic volumes related to existing infrastructure and services, as well as to identify the weakness and bottle-necks in the Adriatic port system. This assessment should enable the creation of sustainable basis for traffic modelling. There are data for assessment of current and potential integration of Adriatic port system with hinterland, regional/local airports, rail network and main tourist destinations. There are some data that helps assessment of regulations related to passenger traffic and assessment of the scenarios linked to the development of: passenger traffic, modal choices, infrastructures and assessment of infrastructure development plans and its impact on traffic flows. Alternatively, the assessment should be adjusted to a finally accepted traffic model for the evaluation. According to these facts database covers several areas (sections) of data as follows:

- Port general information,
- Passengers port maritime traffic,
- Passengers' area and comfort facilities,
- Multimodal connections,
- Environmental issues,
- Demographic and socioeconomic data,
- Data for transport network,
- Data for generalized cost,
- Transport data,
- Infrastructure construction plan,
- Expected traffic flows after infrastructure investments,
- Swot analysis (for ports).

Data modelling helps to facilitate interaction among the database developer and the end user. It was made the relational database model and through the precise determination of the data types there are aligned data types to avoid inconsistency. Part of relations model is shown in Figure 1.

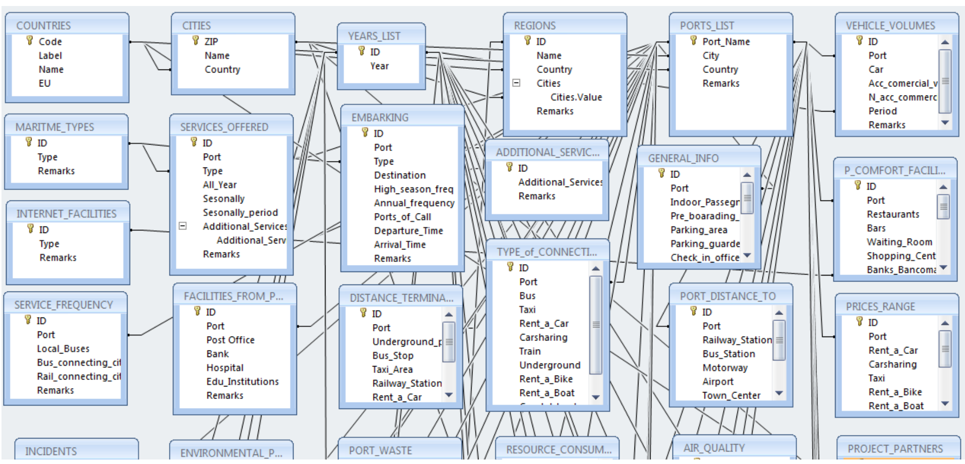


Fig. 3.
Part of Database Relations model

As we can see the relational data model is very sophisticated but DBMS hide the complexities of the relational model from the user and the user sees the database as a collection of tables that can manipulate and query the data. By using DBMS an user friendly interface was designed, customized and developed to allow the end user to interact with the data on easy way.

3.3. Database interface and reports

Due the huge number of collected data users should have user friendly interface with easy navigation through database sections. Microsoft Access forms (Microsoft Access 2016 Runtime, 2016) enable to display records in nice layout that will give users the comfort in controlling data processing tasks and user-friendly environment make EA SEA-WAY database easy to use . Database dashboard is shown on Figure 2.

Fig. 4.
User Friendly Interface (dashboard)

All data are stored in sections according to project objectives and experts who use this database can easly search data and find needed information. Dashboard consists “tabs” for quick access to all data and “Worksheets info” tab give a navigation and section description.

Fig. 5.
EA SEA-WAY database worksheets

To access data there are user friendly forms that opens when choose some worksheet. For example, worksheet 4.1.2 (Passenger Port Maritime Traffic) look like on Figure 4.

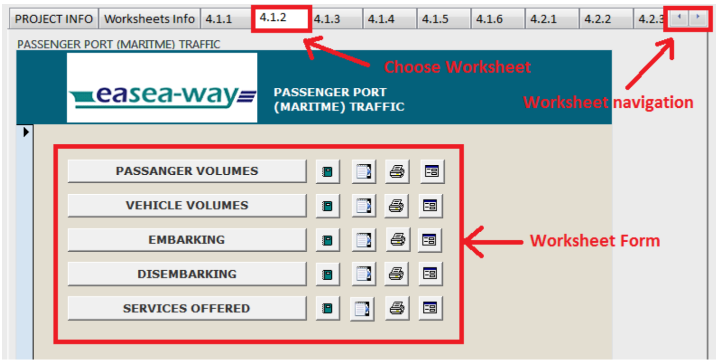


Fig. 6.
Part of Shortcuts Form

Microsoft Access enable users to can take a peek at additional relevant information in the database without changing screens, so they have the right context when reviewing or entering information (Microsoft Access 2016 Runtime 2016). In figure below it is shown one form for inserting and editing data. Forms enable to search data, insert new and edit existing data.

Fig. 7.
Form example for inserting and editing data

Another useful feature of this database are reports that enable the presentation of data. The final appearance of reports adopted to the needs and requirements of the users. Users of database can easily print and export reports in different formats directly from database. By using this database the user can create fully functional reports and can customize it by choosing among many options of style features. Example of database report is shown in figure 6.

easea-way

PROJECT PARTNERS AND ASSSOCIATES

Name	Country	FB	Website	Remarks
Ministry of Transport and Infrastructure	Albania		www.transporti.gov.al	PROJECT PARTNER
TEULEDA	Albania		www.teuleda.org.al	PROJECT PARTNER
Faculty of Traffic and Communication - University of Sarajevo	Bosnia and Herzegovina		www.fsk.unsa.ba	PROJECT PARTNER
Ministry of Transport and Communication Bosnia and Herzegovina	Bosnia and Herzegovina		mkt.gov.ba	PROJECT ASSOCIATE
Coastal Liner Services Agency	Croatia		www.agencija-zolpp.hr	PROJECT ASSOCIATE
County of Primorje and Gorski Kotar	Croatia		www.pgz.hr	PROJECT PARTNER
Dubrovnik Neretva Region	Croatia		www.dubrovnik-neretva.hr	PROJECT PARTNER
Ministry Of Maritime Affairs, Transport And Infrastructure	Croatia		www.pomorstvo.hr	PROJECT ASSOCIATE
Port of Split Authority	Croatia		www.portsplit.com	PROJECT PARTNER
Region of Istria	Croatia		www.istria-istria.hr	PROJECT PARTNER

Fig. 8.
Report example: Project Partners and Associates

Reports in Access can be easily created and that save time for more useful tasks.

4. Database beneficiary and usage

Database stakeholders includes: Project Leader and other Partners (FBs), Ports Adriatic-Ionian Area, Ministries and Regulatory Agencies, Project Manager, Project Office Manager, Project Review Group, Project Teams, Project Team members, etc. Database beneficiary includes (Europe - Adriatic SEA-WAY, 2016):

- Users will be able to get the relevant and systematized information
- Quick search of information required for project activities,
- Access to various statistical data relevant to the project,
- Search for the information needed for a particular analysis on one place,
- View of differences in the relevance of the data for individual ports and regions,
- Users will have access to data gaps in certain ports,
- Reports made in Access Database provide end user with an effective analysing and presentation of data,
- Useful data for further similar research.

EA SEA-WAY database is collection of information that helps in research and project deliverables of different studies such as:

- Assessment of passengers behaviours and maritime traffic flows, traffic volumes & infrastructures and services,
- Assessment of integration of Adriatic port system with hinterland, airports, rail network and main tourist destinations,
- Assessment of the legal framework related to maritime passenger traffic and harmonization proposals in the partner countries,
- Report of common needs and priorities identified related to passenger maritime transport and its integration,
- Report on scenarios and investment needs linked to the development of passenger traffic, modal choices and infrastructures,
- Guidelines for more sustainable passenger mobility.

Developed database could be used in similar projects and by all interested stakeholders while it is available on EA SEA-WAY project web site.

5. Conclusion

EA SEA-WAY database was developed to enable comprehensive view of data that are necessary for project activities as well as the need for storing data on one place and simply manipulation of them. Database has been developed with the aim to have a use-value not only to the EA SEA-WAY project but it can be used in other studies and similar projects that need data related to the Adriatic port system and its integration with hinterland. Database allow subsequent modification, upgrade and customization for future needs.

References

EA Sea-Way 2016. European Adriatic Sea-Way (EA Sea-Way) 2013-2016. Available from Internet: < http://www.easeaway.eu/>.

WP4 2015. Guidelines for a More Sustainable Passenger Mobility-WP4 Assessment of the Adriatic port system and its integration with hinterland.

Čokorilo, O.; Ivković, I.; Čavka, I.; Twrdy, E.; Zanne, M.; Ferizović, A. 2015. Hinterland connection of Adriatic-Ionian Region. In *Proceedings of the International Scientific Conference ZIRP*, 61-67.

Database Software and Applications 2016. Available from Internet: <http://products.office.com/en-us/access>.

Microsoft Access 2016 Runtime 2016. Available from Internet: <https://www.microsoft.com/en-us/download/details.aspx?id=50040>.

VISUALIZATION TOOLS IN SUPPORT OF ROAD ASSET MANAGEMENT

Salvatore Cafiso[1], Sławorir Heller[2], Giuseppina Pappalardo[3], Fabrizia Trovato[4]
[1,3,4] *Department of Civil Engineering and Architecture, Via S. Sofia 64, 95123, Catania, Italy*
[2] *Heller Ingenieurgesellschaft mbH, Otto-Hesse-Straße 19/T9, 64283, Darmstadt, Germany*

Abstract: Managing data of the Asset, such as inventory of geometric features, road sides, signs and markings, road structure data, pavement condition data, traffic volume, accident data, is one of the main issue of a transportation agency in order to apply an effective road asset management. In this framework, road agencies are increasingly reliant on rapidly growing data resources to provide the bases for making critical decisions about how best to allocate available resources to build, operate, and maintain safe, efficient, and sustainable road network. Technologies for collecting data have advanced dramatically, potentially enhancing the availability, accuracy and reliability of data while increasing demands on agency to ensure that their data can be effectively used.
In order to achieve the above goal, road agency at first needs to have software and visualization tools properly developed and applied. The combined use of GIS technologies and innovating software to create strip maps, can be helpful to show, compare and combine inventory and condition data within a strategic process. On the one hand, GIS technologies enable the management, analysis, and display of geographically referenced information at network level, on the other hand strip maps can present several groups of object data which are very important to the decision making process. The paper reports a set of successful "state-of-practice" of maps and strip maps for visualization road asset and pavement condition data and the use of high speed system to provide the condition of infrastructure by a safe, accurate, reliable and cost effective understanding.

Keywords: visualization tools, maps, road asset management.

1. Introduction

Road agencies are responsible for maintaining and improving physical assets to ensure safe, efficient, and reliable travel to the road users. As a result, one of the main functions of a transportation agency is collecting and managing data of the asset, such as inventory of geometric features, road sides, signs and markings, road structure data, pavement condition data, traffic volume, accident data. It is in order to apply a road asset management plan.
In recent years, there has been a substantial increase in both the performance and efficiency of the procedures for collecting data about road infrastructure. On the one hand, the information density as well as the accuracy of individual data are constantly increasing. On the other hand, the costs for data collection and evaluation are drastically decreasing.
Consequently, a rapid rise of databases has been recorded. The sole storage of data in databases and other files is by far not sufficient to support decision making processes. The available data must be provided in such a manner so that decision makers are able to integrate the data efficiently.
The visualization of road data is one of the most important forms of data provision. Appropriate visualizations (by using GIS technology and smart visualization tools) provide support during all phases and levels of the decision making process, i.e. from the operational and the strategic level through to the political level.
This paper presents a set of successful "state-of-practice" of maps and strip maps for visualization road asset and pavement condition data and the use of high speed system to provide the condition of infrastructure by a safe, accurate, reliable and cost effective understanding.
It is divided into three main sections:

- Background information on GIS in road asset management;
- Use of high speed system and Big Data to collect data of asset;
- Innovative data visualization tools to create graphical reports.

2. Background information on GIS for RAM

A geographic information system or GIS helps to store, manage, analyze, manipulate and display data (i.e. road inventory data) that are linked spatially. GIS relates database records and their associated attribute to a physical location, thereby creating a "smart map". Visualization of discrete parts of these data on a GIS map and spatial analysis are possible by layering the data into different "themes". GIS applications can then display the intersection of various "themes", as well as the spatial relationships between various features.
GIS enables integration of disparate data entities using location as the common denominator, visualization of multiple data layers for a selected area or network location, map-based data access for viewing and editing, and spatial analysis involving queries of information based on proximity, route, or geospatial feature. In addition, GIS technology (including global positioning systems or GPS) provides a cost-effective means of collecting geospatially-referenced data in the field of inventory, inspection, and work recording. It also allows the innovative "crowd-sourcing" approaches in which citizens can report locations of asset deficiencies via mobile devices or desktop tools.
As reported in NCHRP Report 800[2] the use of GIS is yielding a variety of improvements in asset inventory control and maintenance management, condition assessment and monitoring, database management. It also helps transportation agencies to manage and carry out Transportation Asset Management.

[1] Corresponding author: dcafiso@dica.unict.it
[2] NCHRP Report 800 *"Successful Practices in GIS-Based Asset Management"*

Transportation Asset Management or TAM is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, and the aim is a better decision making based upon quality information and well defined objective. There are five core asset management processes: identifying the state of the assets, assessing and managing risk, identifying needs and work candidates, developing programs and managing and tracking work.
In this framework, the use of GIS by transportation agency provides three essential ingredients that enable agencies to effectively carry out TAM processes. These are information integration, analysis, and communication; Figure 1 illustrates how they can be applied within an asset management context.
Asset management is by nature data driven and GIS capabilities help agencies to understand what they own, what their needs are, and the best process to apply available resources to meet these needs in a holistic manner.

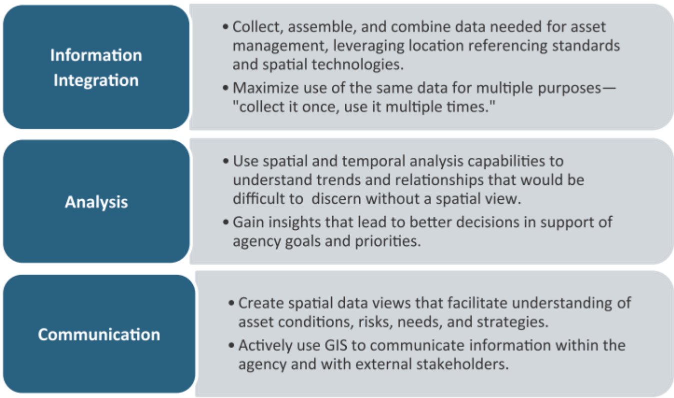


Fig. 1.
GIS capabilities for transportation asset management
Source: (NCHRP) REPORT 800 "Successful Practices in GIS-Based Asset Management".

In order to implement TAM, there is no single way to utilize GIS. However, it is useful to distinguish different levels of implementation in recognition, there are some "basic" capabilities that need to be in place before an agency can move on to more advanced applications.
In general, basic capabilities involve using GIS to visualize some information, such as asset location and condition for pavement and bridge management. Advanced capabilities involve the use of spatial data integration and analysis, specialized GIS enabled applications that support workflow, and more formalized and automated processes for creating, using, and sharing geospatial data across business units.
There are four business process for transportation agency. The first business process for transportation agency is to understand the state of the assets and it is perhaps the most common basic area within which GIS is currently being used. In fact, agencies collect spatially-referenced asset inventory and condition data using various technologies and they use GIS capabilities for inspection planning, data quality assurance, and data display. As soon as the data collection is completed, transportation agencies go into more advanced capabilities of GIS, such as standardized and consolidated data collection efforts across assets, leveraging additional GIS capabilities for data quality assurance and inspection routing optimization, standardizing and automating processes for communicating information about the state of the assets. The second asset management business process involves the understanding of various asset failure mechanisms, assessing their likelihood and consequences, and developing mitigation strategies.
The third asset management business process involves the developing asset maintenance, rehabilitation, replacement, and improvement strategies that address risks and optimize life-cycle costs. Finally, the last asset management business process involves scheduling, delivering, and tracking maintenance and construction work.
In all the business processes transportation agency use both basic and advanced capabilities of GIS, in order to integrate additional data, utilize spatial analysis capabilities for calculating risk scores and involve real-time applications for asset monitoring.
As mentioned above, it is clear that GIS, as a professional software, can help agencies to apply a rational and efficient approach to asset management. However, while some of them have made substantial progress in using GIS for asset management, many challenges still remain related to the development of complete, quality geospatial data, standardization and synchronization of location referencing information across individual asset and maintenance management systems, implementation of data governance structures and processes, and automating spatial data integration and analysis tasks.
In order to face up to some of these challenges, it is important to define some standards starting from the phase of asset data collection. Nowadays, the substantial increase in both the performance and efficiency of the procedures for collecting data regarding road infrastructure has become evident. On the one hand, the information density as well as the accuracy of individual data are constantly increasing. New high speed systems, such as Automatic Road Analyzer, have been developed in order to meet the rigorous data collection requirements of the road infrastructure. On the other

hand, the costs for data collection and evaluation is decreasing drastically due to the introduction of new ways of collecting, managing and analyzing vast quantities of data (big data) collected from and about transport.
The above arguments will be discussed in the following paragraph.

3. Use of high speed system and Big Data to collect data of asset

Data collection and processing are an important and difficult phase in road asset management. It should be performed with specific device or should be carried out as a result of a careful review of open data that are enabling the use of big data in transport asset management.
Different types of data are required for managing transportation infrastructure. Data collection technologies and data needs vary depending on the type of infrastructure element which is evaluated. In general, there are three main types of asset management data

- Inventory data: data that describe the physical element of the road system and road assets and are mostly static in nature;
- Road structure: data that contain information about bridges, tunnels and retaining walls;
- Condition data: data that can describe the condition of assets and these data changes over time.

Typically, road data are collected by technologies and equipments that should guarantee reliability, efficiency and ability of the system to secure the data collected. It will be advantageous if the equipment or methods employed in data collection can collect road data in a single operation so that the collection will be cost-effective and consistent in referencing. Moreover, in order to carry out transportation asset management, it is important to collect other data such as traffic volume, accident data and weather data that can be available in road agencies archives or as open and free data.

3.1. Automatic Road Analyzer

Automatic Road Analyzed 9000 (Fig. 2), a high speed system with a productivity of 200km/die that allow to collect more than fifteen different data streams continuously and at varying capture rates in a single pass at traffic speed.

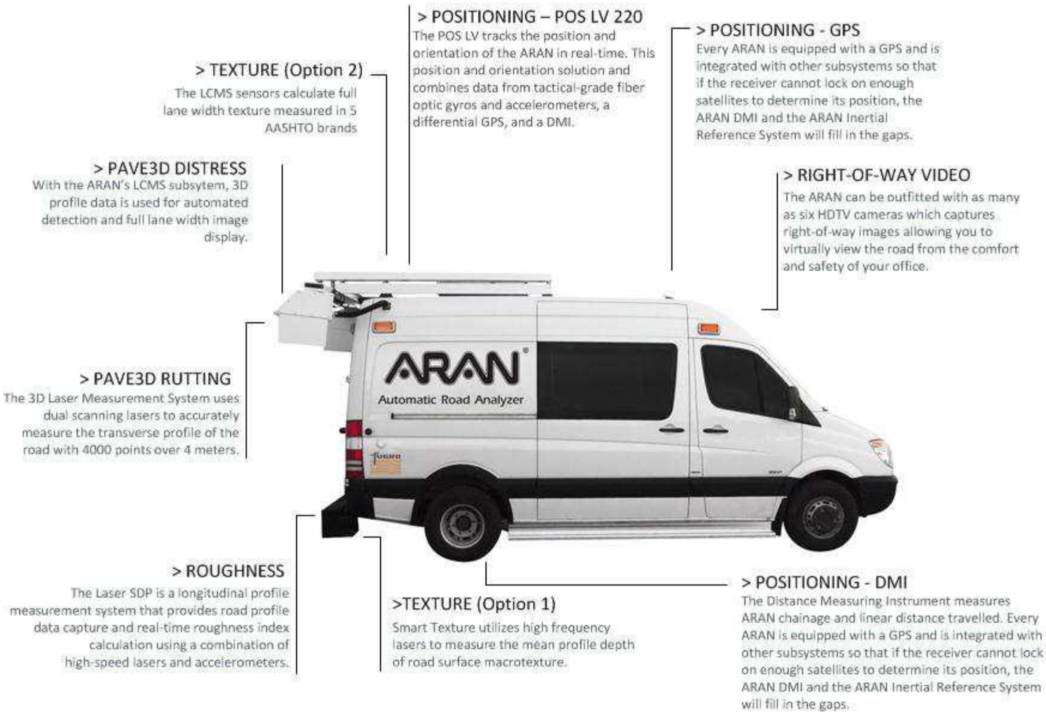


Fig. 2.
Automatic Road Analyzer 9000

ARAN 9000 has recently been acquired by the University of Catania that is currying out an extensive research program for system calibration and output adaptation to a performance based inventory of the road infrastructures.
The ARAN, fully integrated into a high roof chassis, is an advanced pavement data collection vehicle equipped with precision survey system and software able to perform the collection of road's geometric data (cross section, gradients, horizontal and vertical alignment), pavement unevenness, detection and classification of distress and road asset inventory data. It also takes care of the acquisition and filing of the images of accessory elements (for signals, advertising, rights of way, etc.).

All the data returned are accurately located using any geographical reference system (e.g. Gauss-Boaga or UTM) with the help of a satellite differential correction receiver (DGPS), coupled with an inertial platform and they are associated with chainages coming from odometer (DMI), as well.
The pavement detection is carried out by a system which collects continuous 3D images of all type of road surface. The system is composed by Laser Crack Measurement System (LCMS), SmartTexture and SDP Lasers. LCMS is a high speed and high resolution transverse profiling system capable of acquiring full 4m width 3D profiles of a highway lane at normal traffic speed. SmartTexture is a laser that measures the macro texture of the road at speeds of up to 90 kmph. SDP consists of lasers and accelerometer, coupled and installed under the respected wheels paths. The system complies with the ASTM E950-09 standard for the detection of longitudinal profile and International Roughness Index (IRI) post-calculation.
Because of the high rate of acquisition from the LCMS, automatic cracking detection, macro-texture evaluation and rutting measurements are possible. The collected raw 3D pavement data from the LCMS hardware is then derived to more useful information such as texture, cracks and distresses, lane width, transverse profile and rut. The detected cracks are analyzed using a dedicated software (Fig.3) that includes pattern recognition algorithms to determinate the types of distress. Cracking data can then be reported by roadzone, severity level and by aggregating the data to determine length of cracking, width, number of cracks, area of cracking and extent (length of road affected).

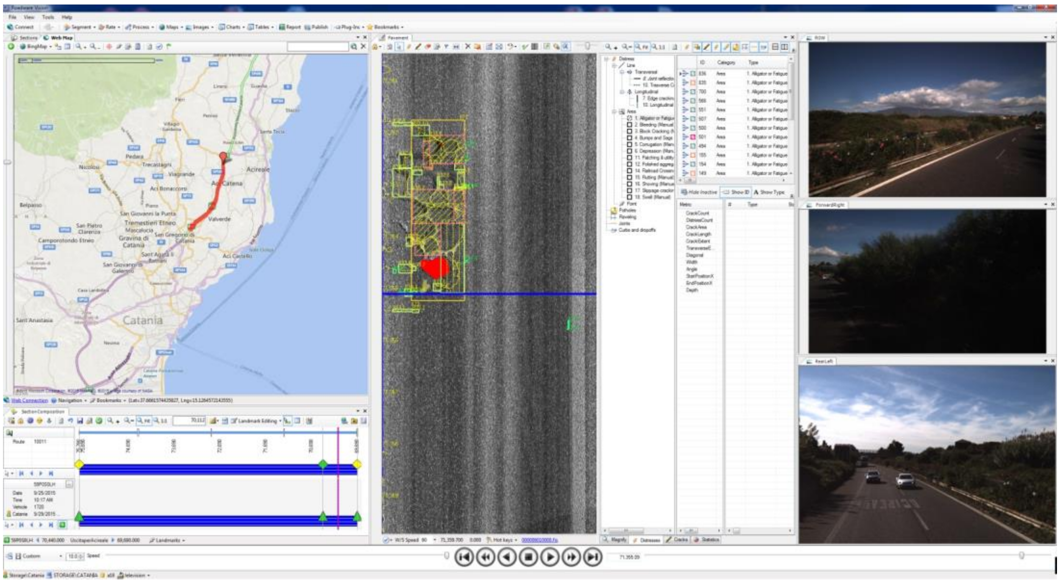


Fig. 3.
Vision software user interface

The automatic crack detection and classification (Fig.4) was calibrated on field data and adapted to provide useful information for post elaboration of performance indices able to characterize the pavement serviceability and maintenance needs (e.g. PSI, PCI). Figure 4 shows improvement in the detection and clustering of different defects after calibration (e.g. density=1.8) from the default values (e.g. density 1.2)

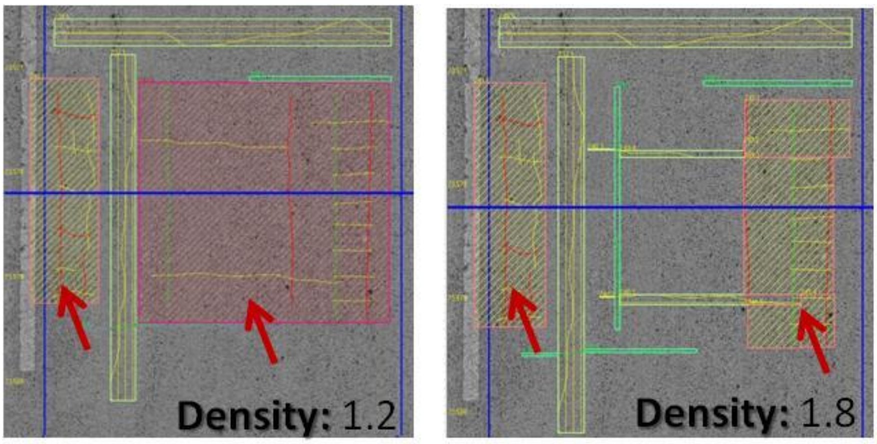


Fig. 4.
Automatic crack detection with density analysis

The asset inventory detection is carried out by using the ARAN surveying vehicle in combination with the HD Videolog system and the Surveyor asset extraction software. The high quality of the two front cameras and one rear

cameras with a resolution of 2750x2200 pixel, ensuring a complete detection of road environment in a field of view of 240°. The Videolog and GPS systems work in sync to provide the geo-referencing of digital images; moreover, the inertial aided navigation system ensures that GPS accuracy is maintained even during long satellite blackouts with sub-meter precision.
The images analysis for extracting road inventory assets is carried out by using a software tool that allows to displays, measures and inventories any road features located along the road and displayed in the image (e.g. lane, shoulder width, sign, marking, roadside, safety barriers, …). More specifically, after calibration of the camera system, it is possible to locate and measure the main dimensions (length, height) of any object along the roadway. Figure 4 reports an example of carriageway measurement and the collection of additional information about pavement and barriers.
A compressive asset inventory was defined able to include not only the base information required by the national guideline for road cadaster (D.M. 2001) but more data needed for checking the compliance with design standards (e.g. geometric design, safety barriers, signs and markings) and finally to estimate the safety performance of the network.

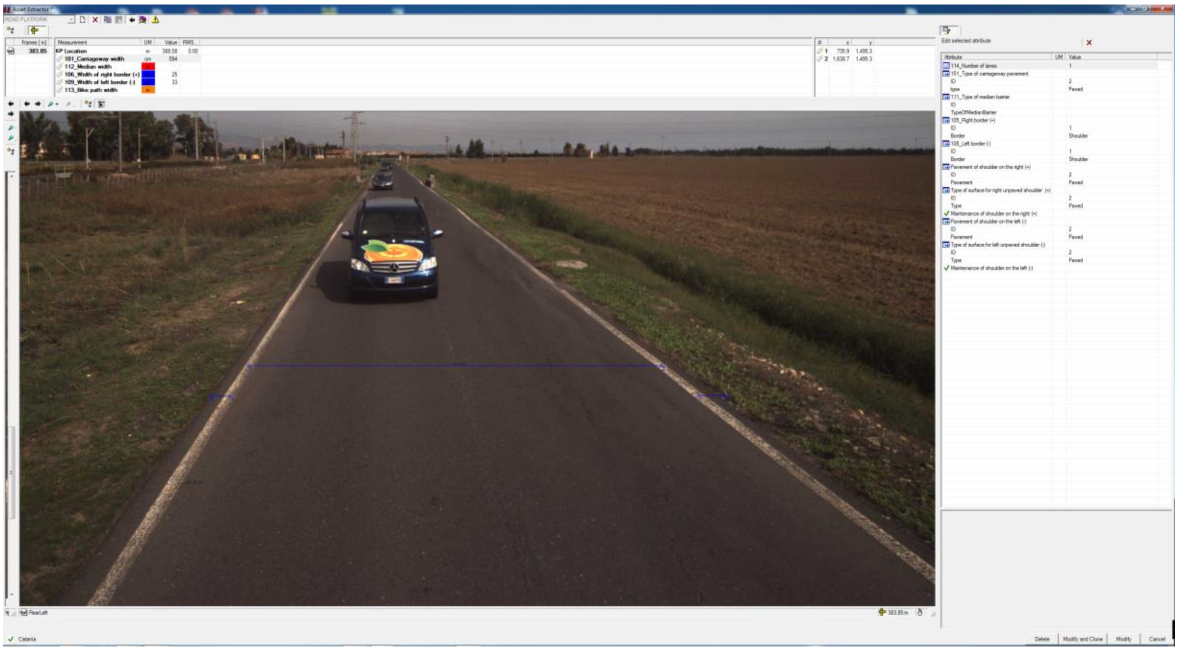


Fig. 4.
Surveyor software user interface

After the HD images have been analyzed all the asset recorded can be extracted as a database file and imported into any GIS tool for the Asset Management System (AMS).

3.2. Big Data

Big data consist of data on a scale or of a complexity that makes it challenging to use. The main features of the scale and complexity of 'big data' include the 3V features:

- high volume – large quantities of data that can range from terabytes up to petabytes in size,
- high velocity – data that must be collected and analyzed rapidly to be useful
- high variety – data consisting of many different forms, often brought together from varying sources

The transport sector has always collected and analyzed large quantities of data, such as data from timetables, traffic news and air schedules. However, recent developments in the quantity, complexity and availability of data ('big data') collected from and about transport, together with advances in computing technology, are presenting new opportunities and challenges to create more efficient and smarter transport systems for people and freight. Using big data can increase efficiency and can reduce the costs to infrastructure and service operators, and can provide better levels of services to users in asset management. Big data offer new opportunities to identify problems more quickly and to reduce costs. Already applications exit where smartphones have been used to crowd-source information about the state of road assets and this information was used to provide insights into traffic conditions on local road networks. These applications provide real time data and can be used to fill the lack of fixed sensors. Transport data are also likely to be further integrated with data from other sectors and an increasing variety and volume of user-generated content. This may enable more efficient and sustainable transport networks as well as more efficient road asset management in the future.
In this framework, it is possible to introduce the project idea of WIKI Roads Map, startup project of the University of Catania, founded by Ministry of Educational: the creation of a collaborative system that uses an organic and innovative data stream originating from road infrastructure and the surrounding area by applying semantic analysis technology for the extraction, collection, integration and publication of data to allow users, both public and private, the acquisition of a greater knowledge, an analysis of the issues relating directly and indirectly connected to it.

4. Innovative data visualization tools to create graphical reports

The data acquired by using high speed systems and collected as big data need to be managed in order to became useful in a road asset management process. The sole storage of data in databases and other files is by far not sufficient to support decision making processes. The available data must be provided in such a manner that decision makers are able to integrate the data efficiently and specifically in their decision making process. The visualization of road data is one of the most important forms of data provision. Appropriate visualizations provide support during all phases and levels of the decision making process, i.e. from the operational and the strategic level through to the political level.

In most management tools, roads are represented as space objects that are visualized primarily on maps along with their attributes by using a set of coordinates. Unlike the spatial representation, the method of linear referencing is easy to understand, does not require sophisticated technology and it allows the user to reference locations in the field using physical markers and identifiers. The progressive standardization and unification of management software in the last years have led to uniform visualizations for all space objects. However, such a universal "GIS-approach" limits the number of possibilities to visualize road specific features in a way that the needs of road professionals can still be taken into account optimally. In fact, GIS visualization can present just a limited groups of data by layering and it serves well to present data and decision results at network level. During both the planning phase as well as the maintenance phase, the road is usually considered as a linear object in the space. Therefore, the localization of all road events and attributes mainly takes place in relation to the road axis, and not by means of geographic coordinates. Information such as traffic load, areas with speed limits, administrative areas, accident sites or road construction is always described in relation to the road, i.e. with help of road millage. Thus, it becomes possible to combine data of a different nature and therefore gain more complex findings relevant for the management. In modern systems, focused on the support of the Transportation Asset Management, roads are represented as linear objects (Fig. 5).

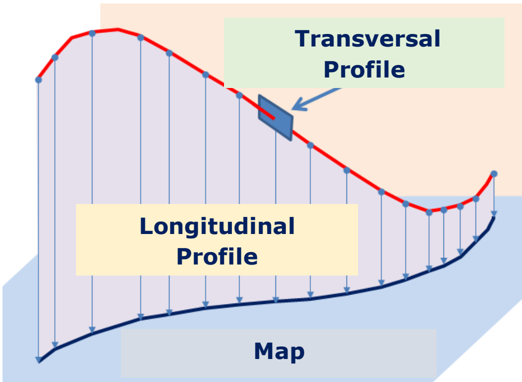


Fig. 5.
Road as a linear object with the three most important perspectives

Therefore, the visualization of the attributes takes the following three perspectives into account: map (Fig.6), cross section (Fig.7) and profile (Fig. 8).

Fig. 6.
Example of a thematic map with condition data of road surface

Thematic maps of road surface condition are the most commonly used graphical reports in Pavement Management Systems. In Fig.6, pavement condition is indicated by four different colors. This provides a very good overview and uses a display technology that presents the condition of all lines on one plot.

In Fig. 7 a strip map with cross-section and surface construction is shown. For planning and management issues, the actual extension of the road usually is irrelevant. Therefore, all presentations operate with several distorted geometric objects in order to focus the attention on what is essential and to supply the information in the desired combination.

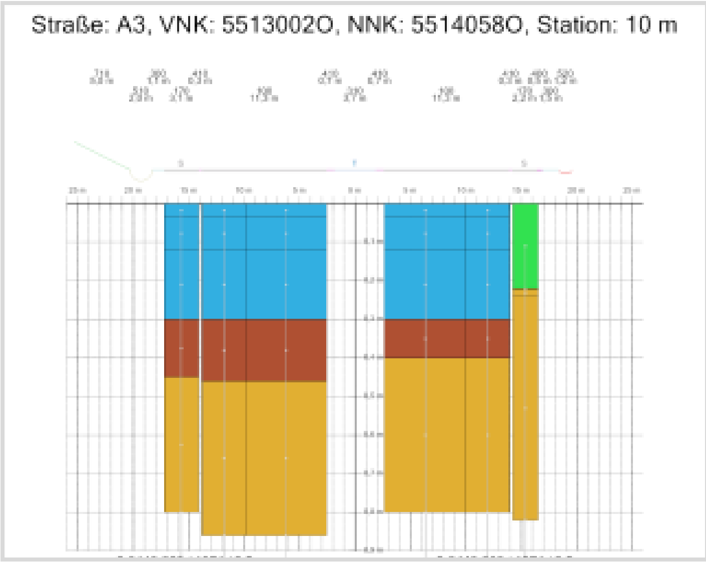


Fig. 7.
Example of a cross section

Fig.8 is an example of strip maps that presents many groups of data within one road section. Such strip maps are useful for the visualization of elementary data (e.g. pavement surface condition). For PMS purposes, road agency need a profile that can show a condition data of short road sections is aggregated to longer sections, as in the profile below.

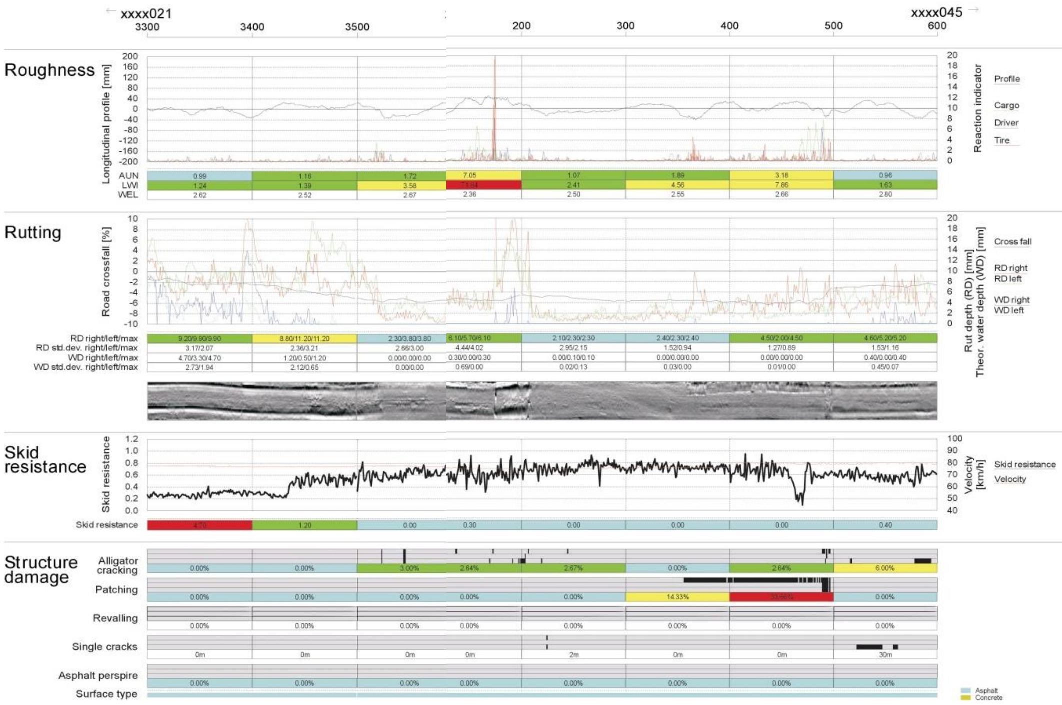


Fig. 8.
Example of a profile with condition data (right side)

It is of great importance that all visualizations correspond with their respective applications at all times. The systems creating the graphics need to be flexible in order to enable adaptations to the users' needs. Furthermore, it is also important to offer an interactive screening of the relevant data in all dimensions. Such visualizations, that are often provided as online services, enable a “virtual ride” through the road network. All elements of visualization, i.e. the map, the profile and the cross section, are being constantly synchronized (Fig. 9).

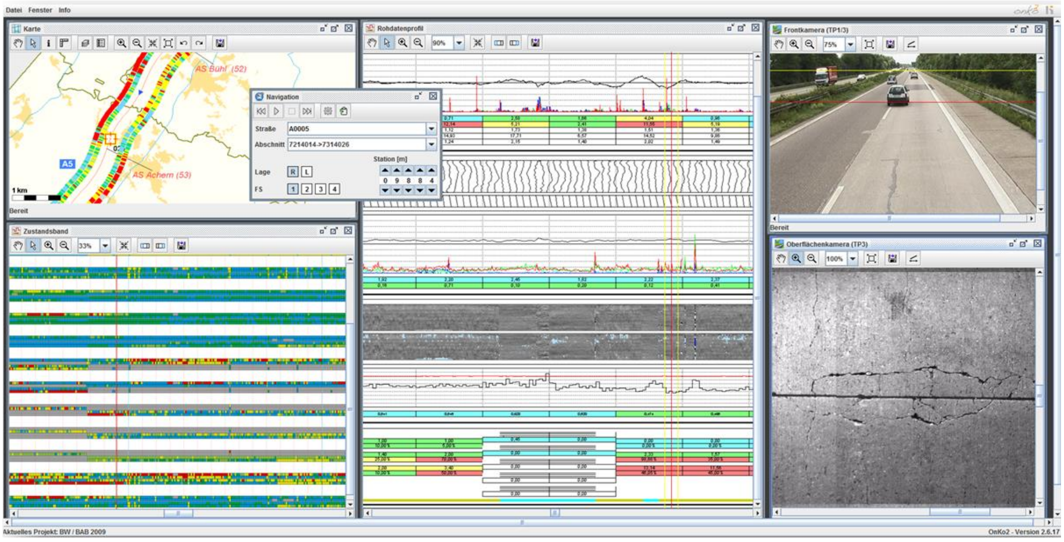


Fig. 9.
Interactive and synchronized representation of road information provided online for the operational level

5. Conclusion

The paper has highlighted present and future opportunities for enhancing the data collection and acquisition from different sources. Apart of the potentialities offered by the new technologies in terms of data quality (high speed collection systems), volume, variability and velocity (Big Data), there is a need to transform data into information useful for Road Asset Management. Appropriate algorithms have to be developed to combine data coming from different sources and visualization tools have to be provided to the decision makers.
A wide range of opportunities for leveraging visualization tools in support of road asset management have been proposed.

- Visualization tools can help road agency in the communication with customers, stakeholders, and decision makers.
- Visualization tools can be used to show the data collected by using high speed system to support an effective Pavement Management program.
- Innovative data visualization tools allow to show a wide group of data such in only one plot, in simple and understandable way.

Acknowledgements

The ARAN was acquired in the context of the RESET Project, founded by Sicilian Region Authority to strength regional research laboratories. The research was founded by WIKI RoadS Map, national start up project founded by Ministry of Educational.

References

Degelmann, R.; Heller, S. 2016. Kennzahlen zur systematischen Beschreibung und Weiterentwicklung der Straßeninfrastruktur im Freistaat Bayern. *Straßenverkehrstechnik*, FGSV.
DM, 2001. Ministero dei Lavori Pubblici- Ispettorato generale per la circolazione e la sicurezza stradale, Modalità di istituzione ed aggiornamento del Catasto delle Strade.
Heller, S. 2004. Consolidating Trust in Road Asset Management by Means of a Dynamic Data-view. In *Proceedings of the 6th International Conference on Managing Pavements*, Brisbane, Australia.
Heller, S.; Wasser, B. 2013. Nutzeranwendung der ZEB-Daten, der IT-ZEB-Server. *Arbeitsgruppentagung Infrastrukturmanagement, FGSV, Köln.*
NCHRP Report 800. 2015. Successful Practices in GIS-Based Asset Management. In *Proceedings of Transport Research Board.*
POSTnote 472. 2014. Big and Open Data in Transport. Available from Internet: <http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-472pdf>.

THE USE OF BIG DATA TECHNOLOGY IN THE ANALYSIS OF SPEED ON ROADS IN THE REPUBLIC OF SERBIA

Slađana Janković[1], Stefan Zdravković[2], Snežana Mladenović[3], Dušan Mladenović[4], Ana Uzelac[5]
[1,2,3,4,5] *University of Belgrade Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, Belgrade, Serbia*

Abstract: Failure to comply with speed limits and speeding belong to the most common unsafe behaviors of traffic participants. Therefore, the speed control represents one of the most effective mechanisms for raising the level of road traffic safety. The velocity analysis must come before the process of road speed control. Nowadays, most of the data on vehicle speeds on public roads in the Republic of Serbia is received from the automatic traffic counters (ATC). If we want to analyze the speeds obtained from 391 counters in the Republic of Serbia, on an annual basis, it is necessary to process over one billion records. This paper proposes an original model of processing data on vehicle speeds that are received using the ATC, in the Big Data technological environment. Big Data technology was developed with the aim to enable an efficient processing of massive quantities of heterogeneous data that arrive faster than the speed of processing, and cannot be handled with the help of conventional tools. The proposed model has been tested on the Apache™ Hadoop® Big Data platform by analyzing vehicle speeds that have been registered by ten traffic counters, positioned in the city of Novi Sad and its surroundings during the year 2015. The indicators were calculated for each counting place using HiveQL query language and Hadoop platform's service, in total and for each direction, annually, as follows: average vehicle speed, vehicle speed standard deviation, median and mode vehicle speed, maximum and minimum vehicle speed, 85. percentile of vehicle speed, distribution of the number of vehicles per speed categories, the number of occurrences of each registered speed at the counting site, percentage of distribution of vehicles by the levels of speeding - for all vehicles or particular category, etc. All calculated parameters were presented graphically and geo-referenced using modern business intelligence tools. Testing has shown that Big Data technology enables more efficient data processing of vehicle speeds compared to the conventional software tools.

Keywords: big data, automatic traffic counters, analysis of vehicle speed, data visualization.

1. Introduction

Observation of road traffic includes the following activities: vehicles detection, traffic counting, length and/or speed measurements, vehicles categorization, etc. Speed management has the task to provide conditions for efficient, cost-effective and safe modern traffic (Subotić et al., 2014). Vehicle speed detection involves the use of various sensors, which almost continuously generate data. The highly developed detection technologies can be classified into three categories: in-roadway detectors, over-roadway detectors, and off-roadway technologies (Martin et al., 2003). In the current play of events, transportation industry cannot meet the rapid growth of data. Also, the traditional data processing systems are becoming inefficient with sporadical failures. On the necessity of solving the problem of processing large amounts of data in transport speak director of Analytics for Urban Insights in the following way: "One of the biggest challenges facing the global transportation industry today is the massive amounts of rich data being gathered but underutilized by urban transportation enterprises" (Rosado, 2014). Traffic engineers accepted the Big Data analytics when they understand that scientific data processing can replace costly projects of construction or reconstruction of roads (Leopold, 2014). Big Data refers to information resource in terms of volume of data, the variety of formats and speed of arrival, that exceeds the possibilities of traditional database management systems (DBMS) (Janković et al., 2016). Currently, the most widely used data sources in traffic are traffic surveillance systems (Shi et al., 2015). Big Data systems are suitable for monitoring the system behaviour, collecting and analyzing defects. These systems offer monitoring of the whole system and its operation in detail which was previously impossible. Intelligent Transportation Systems (ITS) use Big Data with the aim to increase energy efficiency, improve traffic safety, reduce air pollution, relieve traffic congestion, and improve homeland security (Ni, 2015). The advantages of Big Data concepts are improving the safety of traffic and the efficiency of the transportation industry in general (Zeng, 2015).
We have recognized the sensory data, which is widely used in traffic, as a category of data that makes sense to cultivate using the Big Data technologies. Therefore, in this paper we propose a methodology for managing sensor traffic data by using Big Data tools. The methodology includes models of storage, as well as processing, analysis and visualization of data on speeds on the roads in the Republic of Serbia, which are collected by automatic traffic counters. All proposed models are based on the use of Apache™ Hadoop® Big Data tools. Our research includes vehicle speed analysis from nine selected locations on the roads in Novi Sad and its surroundings in 2015. Realized case study showed that Big Data tools are more efficient in managing and processing of sensor data compared to traditional DBMS. Also, it was found that Big Data tools have a feature for simple import or export data to the traditional DBMS.

2. Speed Detection Technologies

Vehicle speed detection is very important for traffic monitoring and it also demonstrates traffic condition. There are cases where the driver does not obey the traffic rules or the speed of the vehicles is beyond the road speed limit. The vehicle that moves faster from the defined speed limit is very dangerous and increases the chances for the accidents. In

[1] Corresponding author: s.jankovic@sf.bg.ac.rs

this section we will present the following speed detection technologies: speed measurement with wireless technologies, radar, laser, laser scanner, pressure sensors and multiple beams. These technologies are applied depending on the existing road infrastructure and environmental conditions.

2.1. Speed Measurement with Wireless Technologies

Intelligent transportation systems use this technology for traffic monitoring as well as to calculate the average speed of the vehicle. (Libelium, 2016). Libelium has launched platform for traffic monitoring which enables system integrators to create intelligent monitoring systems for the urban environment. Figure 1. shows traffic monitoring through waspmote devices. In this case a Bluetooth technology is used for communication of sensor device to make inquiries and detect nearby devices. The sensor data is transferred by a multi-hop ZigBee radio, via an internet gateway, to a server. Meshlium network device running on Linux operating system enables different radio interfaces such as: WiFi 2.4GHz, 5GHz WiFi, 3G / GPRS, Bluetooth. In order to detect a vehicle, WiFi or Bluetooth interface in the vehicle must be set to be visible. These systems can be used to calculate the average speed of vehicles passing between the two sites.

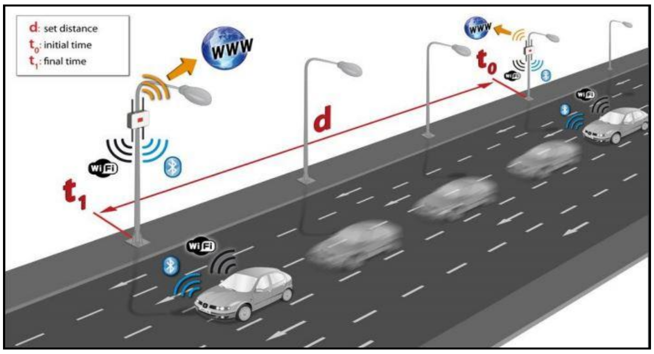


Fig. 1.
Traffic monitoring
Source: Libelium, 2016.

2.2. Speed Measurement using Radar

Radar in traffic is very often associated with speed enforcement system. In all radar devices, speed measurement is based on the Doppler effect. As we can see stationary autonomous speed measurement with radar is shown in Figure 2. The radar antenna transmits a narrow radar beam at a fixed angle to the orientation of the roadway. If a vehicle enters the radiation field from the antenna, part of the radiation is reflected and received back to the antenna. Due to the vehicle’s motion, the frequency of the radiation changes proportionally with the the speed of the vehicle. Therefore, based on the frequency difference between the transmitted and reflected radiation, the vehicle’s speed can be calculated.

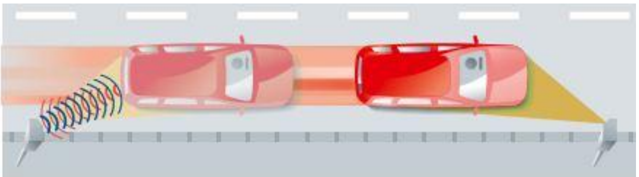


Fig. 2.
Stationary autonomous speed measurement with radar
Source: METAS, 2013.

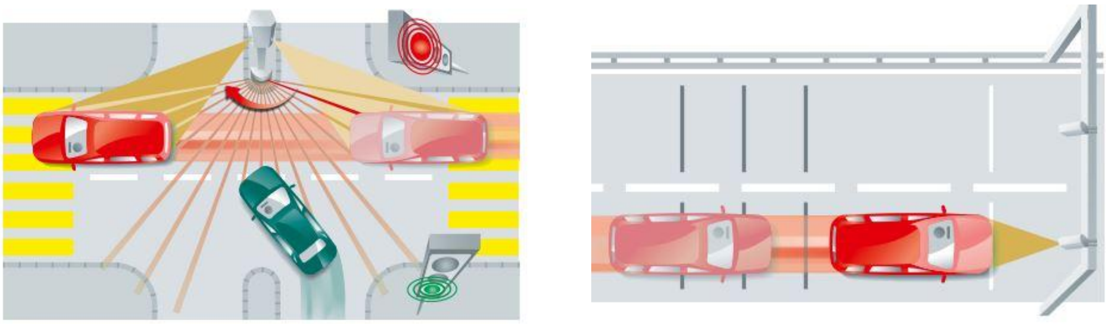
Another generally used technique involves speed measurements using radar device that is worked at a fixed location over a longer period of time. The measurement equipment either uses a fixed installation or it is housed in a transportable measuring booth. This system operates autonomously without any supervision. The recorded speeding violations are either saved locally or transmitted directly to an evaluation centre (METAS, 2013). The disadvantage of such measurement is the use of expensive digital signal processors and complex Fast Fourier Transform (FFT) techniques (Hagargund et al., 2013). This method of measurement is very suitable for speed measurements in intelligent traffic systems.

2.3. Speed Measurement using Laser

When measuring speed using laser, the delay between individual infrared pulses from the transmitter to the vehicle and back to the receiver is measured. Based on this delay, it is possible to compute the distance between the laser device and the vehicle. The distance travelled between two infrared pulses divided by the associated time interval is equal to the vehicle's speed. In theory, it would be possible to perform a speed measurement in this manner using only two laser infrared pulses. In practice, this results in errors, for instance, if the intended target point changes. In order to eliminate erroneous measurements, more series of delay measurements is performed and saved as a part of a measurement procedure. Using a mathematical operation, the vehicle's speed is finally computed from the measured values. The measurement data, date, time of the day and traffic situation at the time of measurement are recorded using analogue or digital image documentation systems (METAS, 2013).

2.4. Speed Measurement using Laser Scanner

Laser scanners have been used for a long time in different monitoring scenarios, for example, at industrial sites or in museums. They are able to detect and record events and trigger an alarm if necessary. Using appropriate evaluation software, it has become possible to measure speeds using laser scanners. This type of devices can be used to monitor a larger traffic area. It is possible to make all types of instant installations such as stationary, supervised, autonomous, fixed and. Laser scanners can also be combined with red light monitoring. Furthermore, they facilitate front and rear shots of the particular vehicle from a booth mounted on a mast. The application of laser scanner as a multifunctional system and speed measurement with pressure sensors are presented in Figure 3a).



a) b)

Fig. 3.
a) Laser scanner as a multifunctional system
b) Speed measurement with pressure sensors
Source: METAS, 2013.

2.5. Speed Measurement using Pressure Sensors

Measurement systems based on pressure-sensitive piezo-electric sensors are used exclusively for speed measurements on highways. In Figure 3b) it can be seen speed measurement with pressure sensors on two-lane highway. They are commonly combined with variable traffic sign controllers. These systems are often used on the road sections where different speed limits are applied in phases to control the flow of the traffic (METAS, 2013).

2.6. Speed Measurement using Multiple Beams

Wavetronix company has developed speed measurement based on the multiple beams. With the two beams generated by SmartSensor HD transmit parallel to each other, create speed trap similar to a dual loop system. This speed trap allows more accurate measurement compared to the radar traffic detectors. Algorithms measure the time it takes a vehicle to move from one beam to the other. This results in highly accurate speed measurements and more precise vehicle classifications (Wavetronix, 2016).

3. Methodology for Vehicle's Speed Data Processing

In this research, we have developed a methodology for processing data of vehicles speed on the roads in the Republic of Serbia, based on the use of Big Data tools. Our methodology includes methods for solving the following tasks: collecting data on vehicle speeds on roads in the Republic of Serbia, storing of collected data, processing the data in order to find useful information and analysis speeds on roads, graphical presentation and geolocation of data.

3.1. Data Collection

To create constructive conclusions about the speeds on the roads, it is necessary to include the speed of all vehicles that were moving on the observed section of the road for at least one year. Automatic traffic counters (ATC) based on inductive loops have an important role in the traffic monitoring. Currently, in the area of Serbia 391 ATC are used (Lipovac et al., 2015). While vehicle passes the induction loop, ATC generates numerous data including the vehicle speed. To count the traffic at the specified locations, among other, the counters type **QLTC-10C** were used (Microbit, 2009). These traffic counters were produced by Slovenian company Mikrobit. Each counter, during the course of the day, "writes" the data into a text file, so that during one year each counter generates 365/366 files. The name of the text file contains a date and the current year when traffic counting was performed. Txt file size is determined by the volume of the traffic in one day at the observed counting place. For each vehicle registered by a counter, one record is created in the text file. Record in the text file, contains the following information:

- Index: a daily number of the vehicles per traffic lane,
- Date and time: in the following format: dd.mm.yy hh:mm:ss,
- Channel: it may have the values from 0 to 3 depending on the order in which the vehicle encounters a loop,
- Lane: it can have values: 0 (a vehicle is in the lane marked as 1) or 1 (a vehicle is in the lane marked as 2),
- Vehicle class: vehicle category,
- Vehicle speed: expressed in km/h,
- Vehicle length: length without the correction factor, expressed in cm.

3.2. Data Storage

In order to store the huge traffic data, we have chosen the Big Data platform - Apache™ Hadoop®. Hadoop is an open-source framework used for storing and processing Big Data in a distributed environment (White, 2015). It contains two modules: MapReduce and Hadoop Distributed File System (HDFS). MapReduce is a parallel programming model for processing large amounts of structured, semi-structured, and unstructured data on large clusters of commodity hardware (Hayes, 2015). HDFS is a part of Hadoop framework, used to store and process the datasets. It provides a fault-tolerant file system to run on commodity hardware.

One of the substantial HDFS features is the ability to upload text files. We should recall the that the data generated by automatic traffic counters are kept exactly in the text files. Therefore, there is no explicit limitation related to the file size! Another important feature of Hadoop platform is that it allows the transfer of data from a text file to its database tables.

This feature can be used only if the data are structured in the text file. Since the data are stored in the text format, we suggest automatic upload of these files to the HDFS. However, for the purpose of analyzing vehicle speed during an entire year, each traffic counter should upload 365 or 366 of these files. It is obvious that this kind of storage is inefficient for large amounts of data. To solve this problem we have created a Windows application in MS Visual Studio 2015. The application provides saving all the data collected from one counter during a year in just one text file. After that, these large text files can be uploaded to the HDFS.

The next step is to create Apache Hive database which will easily import data from uploaded text files. Table in the database should be created for each text file that is uploaded to a HDFS. The table structure must be identical as the structure of the text file. Thereafter, it is necessary to create an Apache Hive query for each table with the command LOAD DATA INPATH. After MapReduce module executes a query, the data from selected text files is transferred to the specified table in the database. When all text files, uploaded to the HDFS, finish import to the Apache Hive database tables, the process of storing data at Big Data platform is completed.

3.3. Data Processing and Analysis

Apache Hive is a data warehouse infrastructure tool designed to process structured data in the Hadoop. It resides on the top of Hadoop to summarize Big Data, and makes querying and analyzing easy. The Hive is built into the “SQL like" query language Hive Query Language (HiveQL, HQL) which allows the manipulation of data in the Hadoop through queries that are almost identical to standard SQL queries. This tool is easy to integrate within the existing tools such as Microsoft Office Excel.

Processing and analyzing of data related to vehicle speeds implies writing and executing of numerous Apache Hive queries. The results of these quiries should include information that may be very useful for the traffic experts in performing an analysis of the speed on the roads. Some of these information are:

- Average speed of vehicles,
- Standard deviation of the vehicle speed,
- Coefficient of variation of vehicle speed,
- 85th percentile of vehicle speed,
- Percentage of vehicles that exceed speed limit,
- Percentage of vehicles that exceeded speed limit with more than 10 km/h,
- Average speeding, etc. (lipovac et al., 2014).

All listed indicators of traffic safety can be calculated for each category of the vehicle. ATC classifies each registered vehicle into one of 10 categories. Additionally, analysis of the aforementioned indicators could be used depending on the day of the week or time of the day.

3.4. Data Visualization

Analysis of vehicle speed means observing dozens of indicators at all measuring points on the roads. We must bear in mind that almost four hundred ATC is placed on the public roads across Serbia. For this reason, it is obvious that a tabular presentation of calculated indicators is not good enough, information would be more usefull if displayed on the road maps. In order to allow the visualization and geo-location of the query results, we propose to make available tables and views from Hadoop database in Microsoft Office Excel 2013. This can be usingMicrosoft Query Wizard. Analysis and graphical presentation of the data can be enabled with the help of Excel's add-ons, Power View and Power Map.

4. Analysis of Speeds on the Roads According to the Proposed Methodology

In the conducted research we have used data obtained from nine automatic traffic counters, that were set in Novi Sad and its surroundings. Presented data are the result of traffic counts during 2015, by automatic traffic counter type of QLTC-10C. Each of the nine counters had 365 files and each text file kept between 4000 and 14000 records. This led us to the following question: how to handle more than 30 million records and draw any useful information from such a large number of data? According to the methodology presented in section 3, we realized the following activities:

1. "Clean up" text files of counters from any invalid records,
2. For each counter, consolidate the content of all 365 text files into a single large text file,
3. Upload each one of the 9 text files into the hadoop big data platform hdfs,
4. Create a database *traffic* in the hadoop platform and use it to store data from the 9 uploaded txt files,
5. Create useful queries against a previously created database in the hadoop platform,
6. Make available the query results that are stored in a database on hadoop platform in a conventional environment for analysis and data visualization with microsoft office excel 2013,
7. Analyze the data and graphically present them in excel.

Activity 4: for each uploaded text file we generated one table in the *Traffic* database. Example of HiveQL query that creates one of those tables in the database *Traffic* are shown in Figure 4.

```
CREATE TABLE bocke(counter_ID STRING, counter_name STRING, X_coordinate STRING, Y_coordinate STRING,
ordinal_number STRING, d STRING, t STRING, loop_number STRING, direction STRING, vehicle_category STRING,
vehicle_speed STRING, vehicle_length STRING)
ROW FORMAT DELIMITED
FIELDS TERMINATED by '\t'
stored as textfile:
```

Fig. 4.
HiveQL query that creates a table bocke in the database Traffic on the Apache Hadoop platform

We “filled” the tables with the data from text files that are stored on HDFS using the HiveQL queries such as one shown in Figure 5.

```
LOAD DATA INPATH '/user/admin/Bocke.txt' OVERWRITE INTO TABLE bocke;
```

Fig. 5.
HiveQL query that transferred the data from text file Bocke.txt on HDFS to table bocke in the database Traffic

After that, we created a table named *all_counters* in the *Traffic* database in which we were able to move all the data from all 9 tables (of the database) with the help of HiveQL (Figure 6).

```
CREATE TABLE all_counters(traffic_counter_location STRING, longitude STRING, latitude STRING, direction STRING,
vehicle_speed STRING)
ROW FORMAT DELIMITED  FIELDS TERMINATED by '\t'
stored as textfile;
```

Fig. 6.
HiveQL query that creates a table all_counters in the database Traffic on the Apache Hadoop platform

On Figure 7 is shown one of the queries that copy the data from one of the tables in database *Traffic* to table *all_counters* in the same database.

```
INSERT INTO TABLE all_counters SELECT counter_name, X_coordinate, Y_coordinate, direction, vehicle_speed FROM bocke
WHERE CAST(TRIM(vehicle_speed) AS TINYINT) > 30;
```

Fig. 7.
HiveQL query that copy the data from table bocke to table all_counters in the Apache Hadoop database Traffic

Figure 8 shows a query that calculates some of the indicators, such as: the mean, maximum and minimum value of the vehicle speed during the 2015. year at a counting place Bocke.

```
SELECT traffic_counter_location, longitude, latitude, direction, ROUND(AVG(vehicle_speed), 2) AS AVERAGE_SPEED,
MAX(vehicle_speed) AS MAXIMUM_SPEED, MIN(vehicle_speed) AS MINIMUM_SPEED,
FROM all_counters WHERE traffic_counter_location="Bocke" AND vehicle_speed > 30
GROUP BY traffic_counter_location, longitude, latitude, direction;
```

Fig. 8.
HiveQL query that calculates the mean of the vehicle speed during the year at a counting place Bocke

By executing the appropriate HiveQL queries on the Apache™ Hadoop® platform, for each traffic counter location, road safety performance indicators related to the speed were calculated. Results of these queries are shown in Table 1. For example, known equation (1), that is used to calculate the standard deviation, we are transformed into the appropriate HiveQL query by which we calculated the standard deviation of the vehicle speed.

Table 1
Road safety performance indicators related to speed by traffic counter location in 2015. year

Traffic counter location	Average speed (km/h)	85th percentile of speed (km/h)	Standard deviation of speed (km/h)	Coefficient of variation	Percentage of vehicle speeds above limit (%)	Percentage of vehicle speeds above limit for more than 10 km/h (%)	Average speeding (km/h)
Alibegovac	52,77	57	8,86	0,17	57,29	18,29	8,58
Bocke	60,72	68	9,38	0,15	89,04	48,49	12,52
Bulevar Evrope 3	72,40	87	15,18	0,21	91,61	76,59	24,73
Klisa	65,11	76	11,32	0,17	92,36	64,14	16,64
Paragovo	65,46	77	12,89	0,20	91,59	62,95	17,35
Šančevi	64,12	75	11,45	0,18	89,32	61,66	16,32
Somborski bulevar	44,07	50	8,62	0,20	19,32	4,24	7,08
Tunel	74,54	88	14,05	0,19	86,44	78,50	27,82
Vojvode Stepe	54,71	62	8,41	0,15	68,45	24,91	8,95

$$\delta = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2} \tag{1}$$

Where; σ: standard deviation of all measured speeds of the vehicles at one counting place during one year (km/h), N: the total number of the measured speeds of vehicles at one counting place during one year, x_i: measured speed of one vehicle (km/h), $\overline{x}$: the mean value of all measured speeds of the vehicles at one counting place during one year (km/h). HiveQL query for the calculation of standard deviation of speed at counting place named Bocke is shown on the left side of Figure 9. On the right side of Figure 9 is shown the results of the mentioned query.

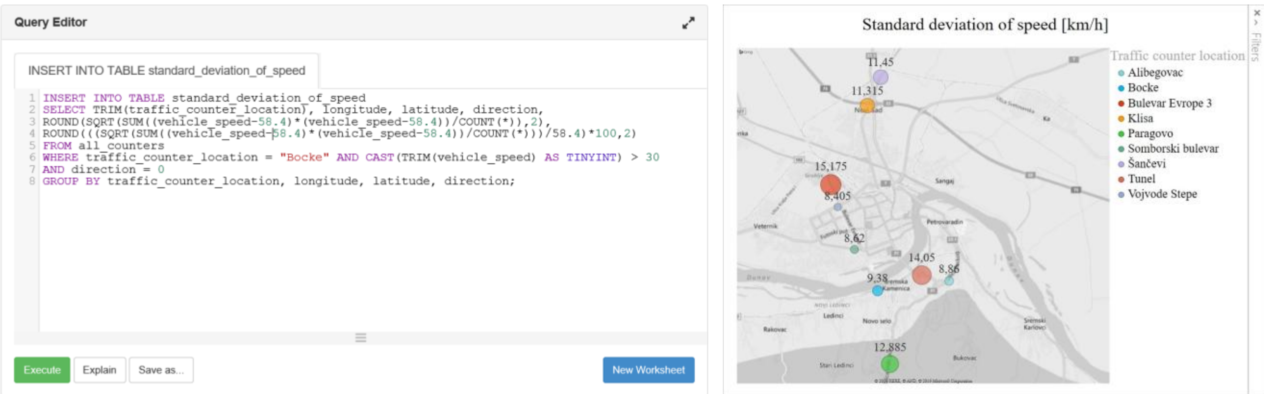


Fig. 9.
HiveQL query for the calculation of standard deviation of speed and his results geolocated on the road map

Figures 10, 11, 12 shows Microsoft Excel Power View worksheets that graphically represent the calculated values some of the road safety performance indicators related to the speed.

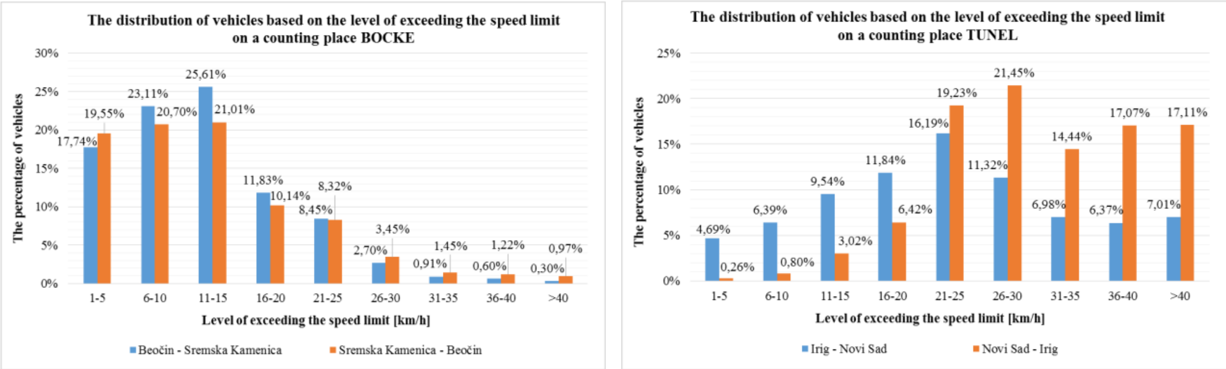
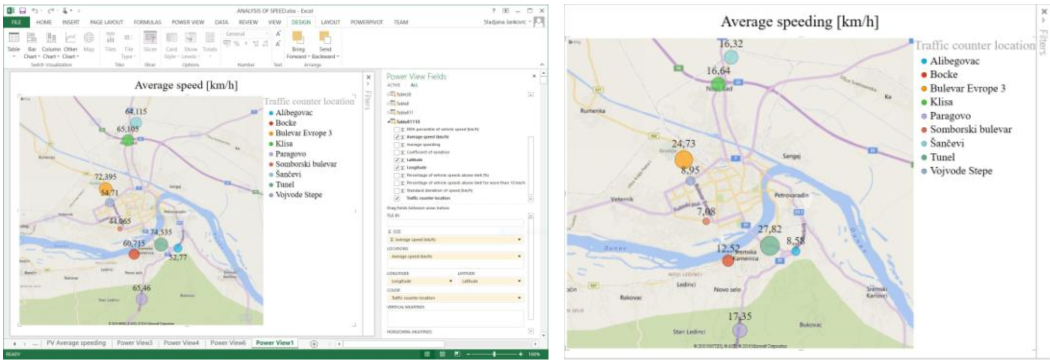
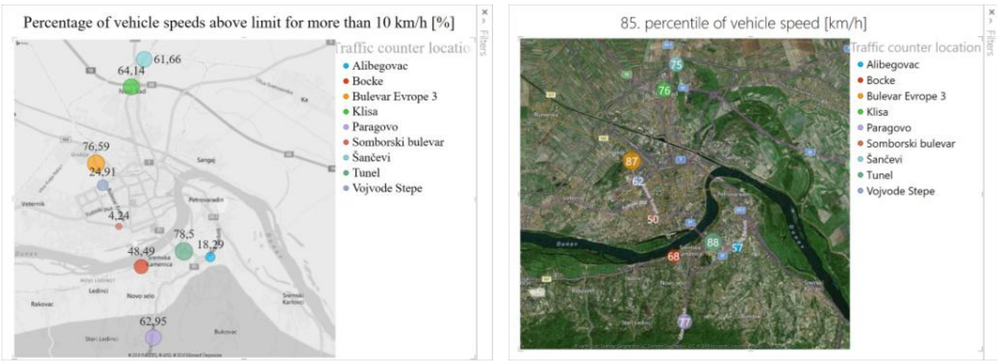


Fig. 10.
The distribution of vehicles based on the level of exceeding the speed limit on counting places Bocke and Tunel



a) b)

Fig. 11.
a) Average speed (km/h)
b) Average speeding (km/h)



a) b)

Fig. 12.
a) Percentage of vehicle speeds above limit for more than 10 km/h (%)
b) 85th percentile of vehicle speed (km/h)

5. Conclusion

In order to become familiar with Big Data technologies in the field of speed analysis, we have developed Big Data solutions that enable the storage, processing and graphical visualization of data generated by traffic counters on the roads and streets in the Republic of Serbia. We used the Apache Hadoop Big Data platform to store and process all the data which could not have been performed using the Excel. Then we displayed the results of data processing, which we made using Big Data technology, specifically the tabular and graphic representation in Excel. In this research, we have been convinced in the power and efficiency of Big Data technologies, especially when it comes to the conduction of "SQL-like" queries over massive amounts of data. In addition, we have been assured in the ability to connect Excel worksheets with the Big Data sources, as well as an enormous capability of Microsoft Office Excel 2013 tools in the field of visualization and geo-location of data. Due to the fact that traffic generates huge amounts of data, which is often necessary to graphically display and geo-locate, the best solution is imposed by Big Data technologies in cooperation with the Excel.

Acknowledgements

This work has been partially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia under No. 036012. The data generated by automatic traffic counters provided by the company MHM - Project from Novi Sad.

References

Hagargund, G.A.; Udayshankar, T.; Rashmi, N. 2013. Radar based cost effective vehicle speed detection using zero cros detection, *International Journal of Electrical, Electronics and Data Communication*, 1(9):1-5.
Hayes, M.A. 2015. Contextual anomaly detection framework for big sensor data, *Journal of Big Data*, 2(2):1-22.
Janković, S.; Mladenović, S.; Mladenović, D.; Zdravković, S.; Uzelac, A. 2016. Big Data tehnologija u saobraćaju: Studija slučaja automatskih brojača, *Tehnika*, 2016(2): 281-288.
Leopold, G. 2014. Big Data Helps Drive Transportation Planning. Available from Internet: <http://www.datanami.com/2014/07/02/big-data-helps-drive-transportation-planning/>.
Libelium. 2016. Meshlium Extreme Technical Guide. Available from Internet: <http://www.libelium.com/downloads/documentation/meshlium_technical_guide.pdf>.
Lipovac, K.; Nešić, M.; Rosić, M. 2014. Road Safety Performance Indicators Related to Speed at Three Locations on Serbian Part of Corridor X. In *Proceedings of the 12th Road Accidents Prevention International Symposium*, 20-30.
Lipovac, K.; Vujanić, M.; Ivanišević, T.; Rosić, M. 2015. Effects of Application of Automatic Traffic Counters in Control of Exceeding Speed Limits on State Roads of Republic of Serbia, In *Proceedings of the 10th Road Safety in Local Community International Conference*, 131-140.
Martin, P.T.; Feng, Y.; Wang, X. 2003. Detector Technology Evaluation. Available from Internet: <http://www.mountain-plains.org/pubs/pdf/MPC03-154.pdf>.
METAS. 2013. Traffic Measurement Technology. Available from Internet: <http://www.metas.ch/dam/data/metas/Dokumentation/METASPublikationen/BerichteMETASPublikationen/Verkehrsmesstechnik%20E.pdf>.
Microbit d.o.o. 2009. Traffic Agent System. Available from Internet: <http://www.zigns.rs/saus/Index.htm>.
Ni, D., 2015. *Traffic Flow Theory: Characteristics, Experimental Methods, and Numerical Techniques*. University of Massachusetts, Boston, U.S.A.
Rosado, W. 2014. Urban Insights Launches Big Data and Predictive Analytics Consulting Practice for the Transportation Industry. Available from Internet: <http://www.urban-insights.com/News/ID/26/Urban-Insights-Launches-Big-Data-and-Predictive-Analytics-Consulting-Practice-for-the-Transportation-Industry>.
Shi, Q.; Abdel-Aty, M. 2015. Big Data applications in real-time traffic operation and safety monitoring and improvement on urban expressways, *Transportation Research Part C: Emerging Technologies*, 58(B):380-394.
Subotić, J.; Jovičić, O.; Simić, M.; Mitrović, Đ. 2014. Upravljanje brzinama na putevima, *Tehnika*, 2014(5):844-852.
Wavetronix. 2016. SmartSensor. Available from Internet: <http://www.wavetronix.com >.
White, T. 2015. *Hadoop: The Definitive Guide*. O'Reilly Media, Inc. U.S.A.
Zeng, G. 2015. Application of Big Data in Intelligent Traffic System, *IOSR Journal of Computer Engineering*, 17(1): 01-04.

INTEGRATED REAL-TIME SATELLITE POSITIONING AND COMMUNICATION SYSTEM FOR RAILWAY APPLICATIONS

Bogdan Pavković[1], Lazar Berbakov[2], Cristian Ulianov[3], Paul Hyde[4]
[1,2] Institute Mihajlo Pupin, Belgrade, Serbia
[3,4] NewRail Centre for Railway Research, Newcastle University, Newcastle upon Tyne

Abstract: An integrated satellite positioning and communication system has been developed within the EU FP7 funded project SPARTACUS, to provide live tracking and coordination of critical assets in a variety of different operational environments. This paper describes the system and the integration of its components to meet the specific requirements of operating in rail transport environment. The functions of each integrated component, as well as the operation of the overall system is presented. The technologies used to generate accurate positional data from the Global Positioning System (GPS) and inertial navigation (for when there is no satellite reception for the GPS system) are described. The article also describes the generation of the positional data, the technologies for communicating the positional data from each monitored asset via wireless propagation of the information between adjacent vehicles to a collection and communication unit on the train. The technologies for the continuous communication of the collected positions of the monitored assets in the train with remote logistics databases using terrestrial, cellular mobile networks, and satellite communications, with a "Smart Link" feature to automatically select the most efficient mode of data transfer are further presented. The integration of these technologies to produce a system to meet the specific requirements for operation within the rail transport environment is discussed. Potential applications of the system in rail sector are proposed and discussed.

Keywords: satellite positioning, GPS, tracking, communications, railway assets.

1. Introduction

In many areas of governmental and legislative policy making there is a general move to encourage modal shift from road transport of goods to rail transport. The main reason behind this is to obtain the environmental benefits of rail transport, which is more energy efficient than road transport in terms of the energy required to transport a given mass of goods, particularly where a collection of consignments can be consolidated onto a single train for a significant portion of a long distance journey, rather than a large number of road vehicles. Consolidating a large number of consignments onto a single train for a long distance journey can be more cost effective, as well as being more energy efficient than individual road transport journeys, at least as far as the cost per kilometre of the transport. However, transporting goods by rail is less flexible than using individual road haulage trucks for the entire journey, and usually involves transhipment costs, especially when either shipper or receiver lack direct access to railway. These transhipment costs might be a significant proportion of the total transport cost and be of a similar order of magnitude to the costs of operating the train itself. Practices such as containerisation aim to minimise the transhipment cost. With containerisation, the transport industry got rid of the manual sorting of most shipments and the need for warehousing. Containerisation also reduced congestion in ports, at the same time significantly shortening shipping time and reducing losses from damage and theft.

In order to manage a transport network effectively, it is necessary to be able to track and trace the consignments within the system; currently, this is generally only done by registering the passing of a container through certain points in the system (such as transhipment yards) and by association with a transport asset, the precise location of which may or may not be known. In order to further improve and optimise the handling of containers and integrate the transport process with the logistics and inventory systems of customers, it is necessary to precisely track of the location and current condition of containers, as well as regularly reporting of all the relevant data over communication networks in real time. Considering the scope of real-time tracking and tracing of goods, there are many potential applications within the railway industry for real-time tracking and positioning of railway assets, including the following:

- Tracking of assets for logistical purposes:
  - Freight customers; integration with business logistics systems;
  - Fleet management; locate fleet precisely without dependence on Infrastructure Manager, precisely track vehicle mileage and usage, and driver performance;
- Traffic management:
  - Locate trains without need for expensive and extensive lineside infrastructure;
  - End of Train Device to locate rear of train and ensure train integrity and track behind train clear.
  - Authorise train movements based on known locations and tracking of all trains: Optimise track flexibility;
- Asset management and condition monitoring (offline CM for traceability, online with communication):
  - Rail industry - location of track/infrastructure features/defects detected by trains;
  - Freight customers - location and condition of sensitive freight; temperature alarms for perishable items, tamper alarms for valuable freight;
- Safety and Emergency intervention and location:
  - Locate trains reporting an incident;
  - Alert assets in area of incident or hazard;

[3] Corresponding author: cristian.ulianov@ncl.ac.uk

- Locate hazardous freight (possible inclusion of condition monitoring).

The problem of precise tracking and tracing of freight trains has already been investigated by different research groups. In paper (Reason, 2010), the authors offer an overview of a concept for implementation of intelligent telemetry system for railway environment, and describes a small scale test implementation of the concept. The authors present details and a set of preliminary proof-of-concept tests of the following functionality: real-time tracking and telemetry of sensorial readings (temperature, humidity, open state), and tackle the issue of ghost wagons – railway elements misplaced in the vast space covered by the railway network of the USA. The paper proposes a reactive system for wireless detection of ghost wagons where the presence of those wagons in circulating trains would detect when passing by certain locations, and the presence of the lost wagons reported to authorities.

The FP7 funded project SPARTACUS (http://www.spartacus-project.eu/) had a goal to provide a complete solution for overall security in emergency management through efficient Location Awareness and Logistic tools that can be deployed during disaster, and which have other applications. The aim of the SPARTACUS project was to design, develop, and demonstrate in real-world scenarios a system for tracking and tracing relief goods, critical transport assets, and first responders in order to assure their safety and efficient crisis management operation. SPARTACUS aimed to provide anytime and anywhere localisation of assets through combined use of existing GNSS and innovative inertial navigation systems. SPARTACUS solutions merged geo-referenced multimedia and situation reports with satellite maps to provide a Situation Awareness and a Decision Support System, and enabled real-time updates and information exchange through a portable and independent communication unit (3G/4G/WiFi/TETRA-alike) with satellite back-hauling.

The paper describes the system architecture, the integration of its components, and the customisation of the system to apply the technologies developed to the rail transport environment and to meet the operating requirements of that application. The technologies that are used to generate accurate positional data from the Global Navigation Satellite System (GNSS) and inertial navigation (when there is no satellite reception of GNSS) are presented. In particular, the paper describes the generation of the positional data, the technologies for communicating the positional data from each monitored asset via wireless medium between adjacent vehicles to a collection and communication unit on the train. The integration of these technologies to produce a system to meet the rail operational requirements is discussed. Finally, present some results obtained during the demonstration campaign at Faurei railway testing centre in Romania.

2. State of the art of intelligent railway tracking and telemetry systems

2.1. State of the art on communication systems

Current state of the art communication solutions supporting railway tracking could be divided in the following groups according to the communication topology deployed:

Infrastructure based: solutions from this group rely partially or entirely on communication infrastructure installed along railway tracks. Available infrastructure enables discrete communication interactions when railway composition enters the limited communication range for short intervals upon train passages. Optionally, continuity of communication can be provided with additional remote communication technologies (cellular and/or satellite). Two types of systems have been mostly described in the literature, i.e.:

a) ***GS1 RFID railway standardised technologies*** (Halas, 2014): GS1 recommends the use of short-range RFID technology (up to 10 m) to dually provide identification and precise discrete position of all railway elements. GS1 RFID system has two parts: RFID readers (provided along railway tracks at limited number of locations with power supply and wired communication available) and RFID miniature end-devices (passive tags, harvesting and reflecting energy from RFID readers) deployed on moving railway elements. When a railway composition passes nearby RFID reader, all elements are uniquely read, identified, and transferred to control centre with the fixed position of the reader. Train timing and position can be inferred from consecutive reader reports.

   *Proficiencies**:***
   - Efficient identification: RFID reader identifies all railway elements even at high speeds
   - Robust: Position independent identification of arbitrary number of tagged elements (up to certain limit) Reduced energy footprint: RFID tags are passive battery-powered; RFID reader is grid powered.
   - Miniature size: RFID tags are size of a tiny sticker ensuring easy placing on railway elements.

   Constraints (SPARTACUS design avoids them):
   - Infrastructure based: RFID readers are provided at many locations, even when tracking is not needed; On the contrary, SPARTACUS provide portable/mobile units to be deployed on demand.
   - Limited tracking resolutions: RFID readers are built at limited number of locations, thus limiting resolution of tracking. SPARTACUS provides any-where any-time real-time continuous tracking.
   - Limited tracking history: passive RFID tags have scarce storing / logging capabilities where SPARTACUS solution provides dedicated memory for necessary logistic and tracking logs.

b) ***RAJANT Railway MESH*** (Hellhake, 2016): RAJANT deploys bridging devices (combined wired and wireless) at fixed positions along a railway track. Devices provide connectivity to both wired backbone and wireless mesh deployed on railway composition. Bridge devices enable tracking and status information upon train passage. Conversely, when bridge devices are unavailable, the rest of MESH deployed at railway composition operates seamlessly, preserving connectivity.

Proficiencies:
- High bandwidth: accommodate advanced applications (tracking data collection, audio, video, etc.)
- Efficient M2M and data collection: devices interconnect mutually, with automatic reconfiguration and reporting path healing in case of node disconnection, thus ensuring robustness.

Constraints (SPARTACUS design avoids them):
- High battery consumption: with greater bandwidth comes increased power consumption
- Limited tracking resolutions: similarly to GS1 RFID the resolution of tracking depends on the density of deployed bridges. Mediated with deployment of additional GNSS and INS equipment on railway composition.

Infrastructureless: solutions from this group are independent from any kind of communication or power infrastructure that makes them excellent match for EM scenarios. Solutions offer independent portable modules that can be deployed on request in different missions or on regular basis for regular railway tracking and logistic.

Tracking device meets remote communication: each tracking device (GNSS with or without INS) features a long distance communication unit (RF, cellular, and/or satellite). Network forms a star topology converging at a central remote collection centre where each tracking terminal serves as communication reporting end-point. Direct local communication (M2M) is not enabled, and eventual exchanges always transit through central communication hub. Currently there is an abundance of solution readily available on the market in variety of forms, such as (listed by the increasing order of available features and/or integration):
- A standalone communication device granting possibility for expansion with external GNSS module;
- Chipsets directly integrating GNSS and cellular capabilities (Kaul, 2014);
- Furthermore, numerous vendors offer terminals for deploy-out-of-the-box with colour displays and graphical interface integrating GNSS with cellular (Cats, 2016), or satellite communication (Dold, 2015) (Niehaus, 2015);
- Finally, a complete solution strives to provide integration with logistic software (web interface and cloud storage) (Amsted, 2016) with eventual integration with sensors (Waukesha, 2015);

Solutions from this group offer standalone devices with independent means of communication for each tracking unit - a high-end solution that is highly adapted for individual and important assets tracking. Nevertheless, they are not necessarily well adapted to massive railway container shipping since similar solutions do not scale well due to their overall price, higher power consumption and battery maintenance. SPARTACUS tackles these challenges by decoupling independent remote communication from low-power local wireless sensor collection.

2.2. State of the art on tracking systems

Train and container localisation/positioning is a crucial task for railway transport, especially in relation to safety-relevant issues or safe-critical operation (either automated or not) of special assets and goods. Nowadays, train positioning along the railways net is accomplished by ground fixed installations, typically track-side equipment, in combination with positioning sensor systems placed on-board the trains (for details see the description of the European Train Control System, ETCS, Level 2 in (Terry, 2012)).

The functioning principle of these types of systems (Bailey, 1995), (Albrecht, 2013) is basically based on wireless exchange of data and is the following: beacons, devices that behave like transponders, are placed along the track at known pre-established positions. They can be considered as Radio Frequency IDentification (RFID) devices and can be either of passive type, working as inductive transponder without need of electrical power supply, or active devices powered by batteries. When the train crosses a beacon, its on-board equipment triggers the beacon’s transponder which transmits a radio data flow to the train containing its position fix and other information. By receiving these data, the train equipment can determine its position at the time of data reception, within a certain accuracy depending on the train speed and the accuracy of the beacon known position. In addition, the passage of the train over the beacon, hence the train position, can be acquired by the train traffic control system via the wired link connecting each beacon to the train control centre network.

The positioning of a train via beacon, as described, has three main disadvantages:
- it is intrinsically discrete in time, hence no continuous position of the train is available;
- it is affected by data latency depending on the train speed, so reducing the accuracy of positioning;
- it requires a ground infrastructure.

As to the first point, the adopted method to obtain a continuous position solution of the train is to use the data from an on-board odometer (wheel counter) to propagate in time the position estimate between two fixed balises. The accuracy of the propagated position typically decreases with time (or distance between two fixes) due to possible wheel slips or the drift caused by the imperfect knowledge of the circumference of the wheel.

In order to completely overcome the three listed drawbacks, some interesting alternatives have been proposed (see PiLoNav project in (Mahlknecht, 2007)) - the main one is the introduction of a train positioning system based on only on-board available data and independent by any external ground infrastructure. This system is designed on a multisensor on-board positioning system that performs a data fusion between GNSS data, Inertial Measurement Unit (IMU) data, and additional sensors such as an optical sensor and a laser scanner.

The optical sensor is based on LEDs that illuminate the railheads during the train motion: diffraction gratings processing allow for a quite accurate and slip-free train speed measurement; speed numerical integration provide the run distance. The laser scanner is used in order to determine transversal (lateral) position of the train with respect to the direction of motion, so providing an automatic rail track identification, together with side signals recognition. This sensor redundancy has a twofold aim: 1) to improve the position accuracy by a calibrated data fusion algorithm that weights in an optimal way the information provided by each sensor in order to get the best position solution; 2) to increase the reliability and robustness of the system. In addition, a map matching process can be accomplished to force the train position solution to fit to the real rail shape, so further improving the accuracy of the positioning. The disadvantage of the map matching consists in the difficulty to equip each train with a georeferenced, detailed, updated and accurate map of the rail net, whose availability is not always guaranteed.

On the other hand, single container positioning is not a much exploited field. The most up-to-date widespread solution consist of RFID passive tag installed on the wall of a container that provides to an operator passing in front of it some status data such as Identifier, Temperature, and so on. More advanced devices also include a tracker based on low cost GNSS receiver that can provide a rough container position estimate, in case of GNSS signal availability.

The container and train positioning system proposed in this paper is based on a *multisensor framework* too, together with a *data fusion process*. Nevertheless, in the proposed system no pre-stored maps are needed nor external infrastructure or additional on-board sensors in addition to those already envisaged by current projects as PiLoNav. As opposed, a data fusion between a high quality on-board freight train positioning system and low cost container tracking units carried by the wagons of the train is performed. This data fusion exploits the kinematics constraints of the train geometric configuration, used as an additional source of information, and aims to provide better, refined and more accurate positions of both the already accurate locomotive position (which integrates good quality GNSS data and odometer/IMU data) and that of the containers (that is not good when considered singularly).

One of the main features of the proposed system is that the increased accuracy derived by the multisensor-kinematic-constrained framework increases also the robustness and the integrity of the position solution and the system safety.

3. SPARTACUS system architecture

This section presents the SPARTACUS system architecture. Figure 1 shows a holistic overview of the main composing building blocks, their mutual relationship, and points of interaction with intended end-users. SPARTACUS system architecture should serve as a clean graphical overview and a simple starting point to understand how the system is conceived and how information flows without going to the detailed technical specifications. Bidirectional information exchange flows along both wireless and wired networks and links. Specific technologies, standardised protocols, and supported interfaces are concealed in the SPARTACUS overall architecture and are presented in more details in the subsections dedicated to the specific SPARTACUS subsystems.

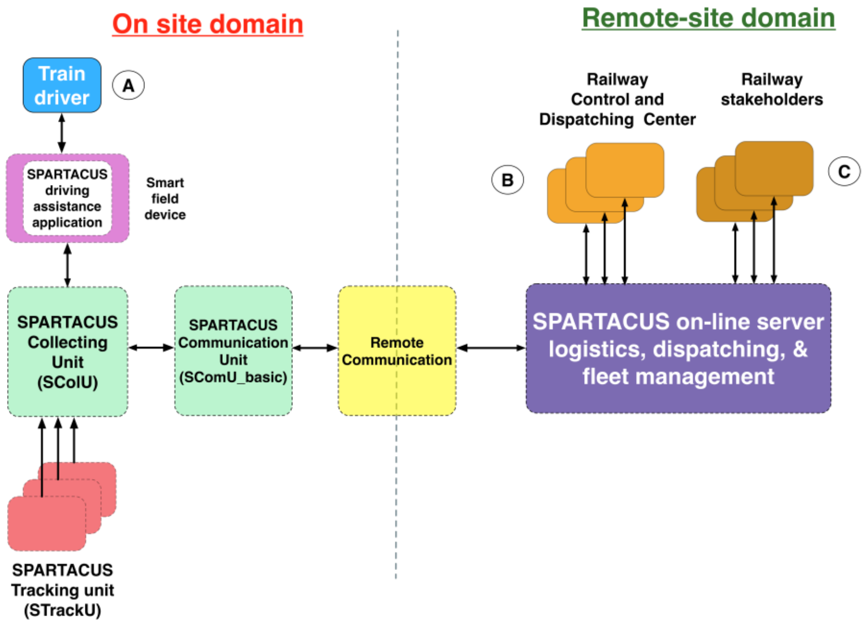


Fig. 1.
SPARTACUS system architecture

SPARTACUS architecture was kept as general as possible to be easily upgradable and to respond to applications with similar needs. SPARTACUS architecture follows modular design, where each building block regroups technologies providing complementary or similar functionalities.

SPARTACUS system architecture takes into account a clear differentiation between on-site and remote site domain as defined by user profiles. On-site segment can be seen as the sensing and acquisition of information about transport and disaster site environment itself. On-site segment includes local and remote communication means along with low-bandwidth clients for visualisation and direct situation feedback. Remote site can be seen as a centralised point for information collection, further analysis, processing, and information fusion for situation awareness and decision support.

3.1. Local communications subsystem

The communication architecture of the SPARTACUS Collection Unit (SColU) is shown in Figure 2. The focus is on communication channels offered by SColU and interconnection points with other units in the SPARTACUS system.

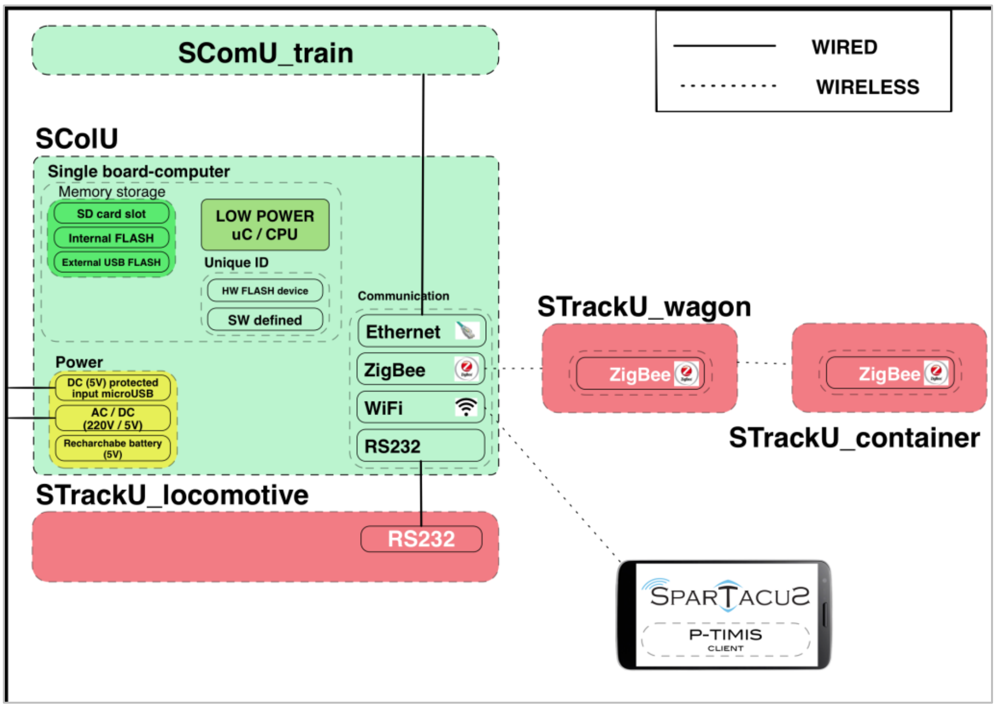


Fig. 2.
SColU communication architecture

The aim was to build, collocate, and interconnect in the same protective suitcase/box several units - SComU, SColU, and STrackU (SPARTACUS Communication, Collection, and Tracking Unit respectively). Particular design choice stems from the strategic importance of the locomotive as the principal element in the transport composition holding a train driver. SColU provides several means of communication to interconnect with the rest of the system. SColU connects over wired link to the elements in its physical vicinity. Bidirectional information exchanges between SComU and SColU will be carried over a standard Ethernet connection supporting transfers of potentially large volumes of collected tracking and tracing data. On the other side, SColU interfaces to STrackU_locomotive (developed as a stand-alone unit, and produced by *SBG Systems*, a partner in SPARTACUS consortium), over a standardised RS232 serial link. Serial wired link (RS232) provides sufficient bandwidth to accommodate periodic samplings of tracking and tracing information at maximal rate of 200Hz. Lower rate readings can be directly configured at the unit. On demand asynchronous access (triggered request) is equally available. SColU provides as well wireless interfaces for elements that are either physically located further away or when it is more favourable and practical to connect over wireless channel.

Highly dynamic railway environment with frequent changes of transport asset composition (wagons and containers leaving / joining) is ill-suited for wired cable connections. SColU provides both a standardised WSN (ZigBee) and WLAN (Wi-Fi) connections. SColU accommodates a ZigBee PAN coordinator (gateway / sink) that serves as a central point for collection of tracking and tracing data from STrackUs (wagon and containers) equipped with ZigBee modules accordingly configured as ZigBee routers and ZigBee end-devices, respectively. Low-power, low-bandwidth ZigBee technology offers a sufficient throughput (a nominal 250kbit/s) to accommodate a periodic tracking and tracing reporting from STrackUs located on wagons and corresponding containers. Frequency of STrackU on wagons and containers will be at lower frequency compared to those on the locomotive. SColU can provide a secured Wi-Fi - IEEE 802.11 b/g/n.

When SComU is available and connected to SColU through a primary Ethernet link, a WLAN AP will be provided only by SComU for energy conservation reasons. Otherwise, it will be provided by SColU, configured and limited for exclusive communication between authorised railway personnel and local server hosted at SColU. A primary user, e.g., the train driver, will be able to monitor the state of the railway composition in real-time through the mobile application on COTS smartphone. Furthermore, WLAN AP provides an efficient way for any authorised personnel to securely access and download a local historical copy of collected tracking and tracing data stored on SColU, both when deployed on a train and post-mission. Furthermore, SColU will provide a backup wireless link to connect to SComU if primary Ethernet link is not available or not working. It could be equally performed either through an additional Wi-Fi interface or by using the same physical interface but enabling a virtual interface. A trade-off between energy consumption (several independent physical interfaces) and bandwidth repartition (single shared physical interface) needs to be further established during the implementation phase.

3.2. Remote communications subsystem

The network architecture of the SPARTACUS Communication Unit (SComU) is depicted in Figure 3.

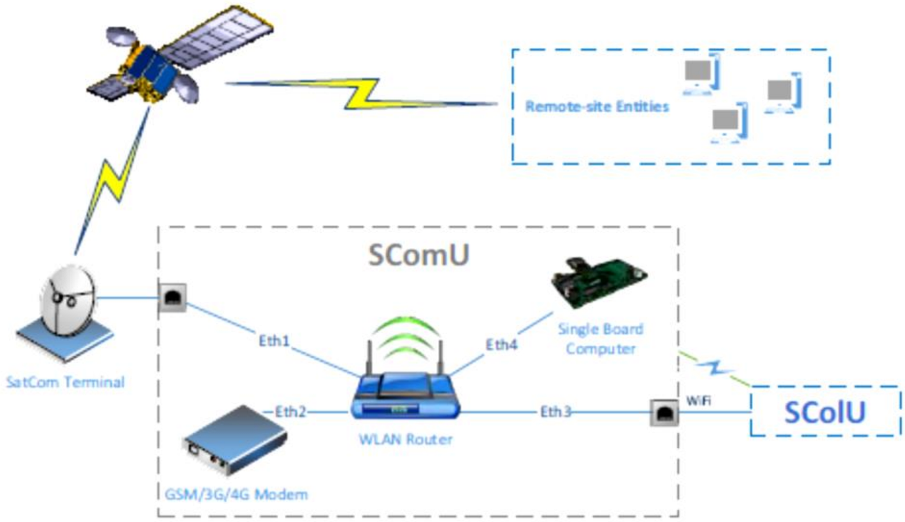


Fig. 3.
SComU remote communication subsystem architecture

The SPARTACUS Communication Unit (SComU) consists of several network elements that all aim at interconnecting units together and also allowing the support of different networks. The communication towards the remote-site entities is made through remote communication based either on a terrestrial network when available, or on a satellite network. The connection to the terrestrial network is done using a Long Term Evolution (LTE) modem which simply acts as a client in the 4th Generation (4G) network, exactly like a 4G smartphone would do. This LTE modem allows interconnecting other devices via Ethernet such that it is possible to access the 4G network. In our case it is foreseen to connect the LTE modem to a router such that the 4G connection is shared with the other devices connected to that router. In the same way, the satellite communication (SatCom) terminal consists of a satellite modem and of an antenna also allowing sharing its connection via Ethernet. This way, the SComU can access the “outside world”, also named the Wide Area Network (WAN), using either the satellite connection or the terrestrial 4G connection. It is foreseen, in the framework of the rail application, to make use of the Broadband Global Area Network (BGAN which is an Inmarsat service) for the satellite connection. BGAN offers the possibility to benefit of a bandwidth in the magnitude of 256 kbps (upload and download) while using relatively small satellite modem and satellite antennas (patch antenna in the L-Band). In terms of communication, the SComU shall also provide a local wireless network based on the conventional and well spread Wireless Fidelity standards (Wi-Fi). The SComU also supports local wired connections based on Ethernet (conventional RJ45 cables). Both Wi-Fi and Ethernet are provided by a Wireless Local Area Network (WLAN) router which acts as a central node of the star network topology.

3.3. Positioning subsystem

Positioning subsystem (STrackU) fulfils the following roles: continuous tracking and tracing (combined use of GNSS and INS readings), communication with SColU, and finally acquisition of local sensor readings (container monitoring e.g., temperature, humidity, or detection of a door open status).
STrackU will dispose with both wired (RS232/RS433) and low-power wireless (ZigBee) communication means. Both means offer security mechanisms to encrypt and securely transfer data. Wired connection will be used for the case where STrackU and SColU can be collocated in the same casing. Majority of communication functionalities described for SColU (periodic reporting and triggered requests) will apply as well for STrackU to complete bidirectional communication flow. Entire WSN ZigBee network will follow a convergecast tree topological structure, specifically optimised for collecting periodic reports from potentially large number of end-devices (STrackUs). Additional

advantage of convergecast topology is an intuitive aggregation strategy - intermediate levels, (STrackU_wagon) could decide to fuse tracking and tracing readings when they do not differ substantially. Instead of simply forwarding of each single packet from STrackU_container, energy and bandwidth savings could be achieved by intelligently combining several packets and forwarding them conjointly. Different "flavours" of STrackU are building a convergecast topology by fulfilling a specific device role defined by the ZigBee standard.

- STrackU_locomotive with SColU, as a collecting gateway is configured as a ZigBee PAN coordinator and fulfils several roles: apart from collecting tracking and tracing readings from the entire WSN, it authorises the joining process for other new coming devices and remotely polling other subordinate nodes;
- STrackU_wagon was configured as ZigBee Router, and it serves as an intermediate device, relaying end-devices with a gateway. Additionally, it could provide aggregation feature for sub-network nodes;
- STrackU_container was configured as a ZigBee End-device due its logical belonging to the end of reporting chain. It generates periodic reports of both tracking readings, as well as of available environmental data provided by external sensors (not inherent part of STrackU, optionally provided by end-users).

4. Test implementation of the SPARTACUS system in railway environment

The application of the technologies developed within the SPARTACUS project to the railway environment has been initially tested by a trial installation carried out at a full scale railway test site. These tests are described in the paper "Testing and Evaluation of Real-time Satellite Positioning and Communication System in Rail Transport Environment" by Hyde et. al., which was presented along with this paper at the ICTTE 2016 Conference. That paper describes the successful installation and testing of a railway vehicle positioning and position communication system using the technologies described in this paper. It also describes how, after the adaption of the system to railway conditions and environmental characteristics, and refinement of the system hardware and software configuration, it was shown that the system was able to communicate the position of all of the vehicles in the train to a remote location in near real-time. In those tests, the accuracy of the positioning data was demonstrated to be sufficient for the overall aims of the project, which is to achieve critical asset tracking for logistical purposes in a variety of applications.

5. Full scale demonstration of the system

Since the initial testing and adaption of the system, which was described in the paper referred to in the previous section, a further test installation and demonstration of the system has been carried out, and some preliminary results are available. The demonstration of the system was performed in September 2016 at Romanian Railway Authority (AFER) testing centre, in Faurei, Romania. The system was tested on the big ring of the testing centre, which has a total length of lines of 13.7 km. The train composition consisted of a diesel locomotive and two wagons, where the system components have been installed as follows:

- SComU+SColU have been installed in the locomotive cabin with satellite and GPS antenna mounted on the roof;
- 4 STrackU have been installed on wagons (by using magnetic pads), where three of them were configured as STrackU_wagon and one configured as STrackU_container (as shown in Figure 4).

Locomotive and 2 wagons used for testing

SComU and Ellipse module
installation in the locomotive

Installation of the STrackU on the roof
with magnetic pads

Fig. 4.
Testing setup at full scale demonstration at Faurei test centre

Before the testing, all the devices have been switched on, and both local ZigBee and remote connection over LTE were automatically established. Once the train started its ride, the train path could be observed on the CTAT web portal, as shown in Figure 5.

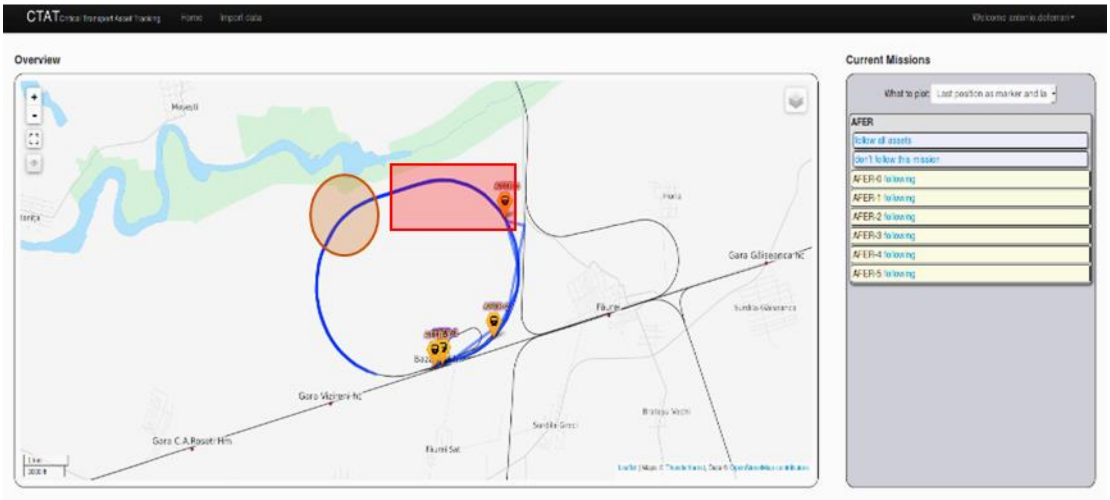


Fig. 5.
Train path observed on CTAT web portal

During the ride, a GNSS signal outage was simulated by disconnecting the antenna for two minutes where the train was correctly tracked during the whole outage period (red rectangular zone in Figure 5). An outage of the LTE network between two base stations (orange circular zone in Figure 5) was also for a short period, during which SComU automatically switched to satellite link, providing uninterrupted network connection between on-site and remote-site domains. As can be seen from Figure 5, the track perfectly followed the railway track even in periods of GNSS signal outages.

6. Conclusion

An integrated tracking and communication system to be used for continuous railway assets tracking was developed, and is presented in this paper. The tracking is provided by intelligent sensor fusion between GNSS and INS that provides tracking even in locations with GNSS signal outage such as urban canyons and tunnels. The communication is divided into local and remote domain in order to provide a good balance among energy efficiency, cost and robustness. The system has been tested at Faurei railway testing centre in Romania, where it proved to be highly robust to GNSS and network signal outages, at the same time providing high accuracy and continuity in train tracking.

Acknowledgements

The development of the systems presented within this paper and the testing program were funded and carried out as part of the EU FP7 project SPARTACUS. More information, including the public reports and deliverables, can be found on the project website: http://www.spartacus-project.eu/.

References

Albrecht, T.; Luddecke, K.; Zimmermann, J. 2013. *A Precise and Reliable Train Positioning System and its Use for Automation of Train Operation*, IEEE International Conference on Intelligent Rail Transportation (ICIRT).

Amsted, J. 2016. *Ionix Railway tracking and logistic solution*. Available from Internet: <http://www.amstedrail.com/ionx>.

Bailey, C. 1995. *European Railway Signalling*, A & C Black.

Cats, O. 2016. *Telit Pairing GNSS+Cellular devices*. Available from Internet: <http://www.telit.com/iot-modules/>.

Dold, J. 2015. *Leica GeoSystems GNSS/3G solution*. Available from Internet: <http://www.leica-geosystems.com/en/Leica-iCON-gps-60_97920.htm>.

Halas, E. 2014. *GS1 RFID/EPC Standards for Railways*. Available from Internet: <http://www.gs1.eu/?content=1008>.

Hellhake, P. 2016. *Rajant Railway Mesh solution*. Available from Internet: <http://www.rajant.com/applications/transportation/>.

Kaul, P. 2014. *Huges BGAN terminal with external GNSS support*. Available from Internet: <http://www.hughes.com/technologies/mobilesat-systems/mobile-satellite-terminals/hughes-9502-bgan-m2m>.

Mahlknecht, S.; Madani, S.A. 2007. *On Architecture of Low Power Wireless Sensor Networks for Container Tracking and Monitoring Applications*.

Niehaus, R. 2015. *Iridium NAL SHOUT nano device*. Available from Internet: <https://www.iridium.com/products/NAL-SHOUT-nano-Personnel-Tracker.aspx?productCategoryID=11>.

Reason, J.; Chen, H.; Crepaldi, R.; Duri, S. 2010. *Intelligent Telemetry for Freight Trains*, Mobile Computing, Applications, Services, Berlin, Germany: Springer-Verlag, 35: 72-91.

Terry, N. 2012. *ETCS for Worldwide Train Control*, IRSE Australasia Technical Meeting.

Waukesha, M. *Lat-Lon Railway tracking and logistic solution*. Available from Internet: <http://lat-lon.com/solutions/asset-category/freight-railcar>.

TESTING AND EVALUATION OF REAL-TIME SATELLITE POSITIONING AND COMMUNICATION SYSTEM IN RAIL TRANSPORT ENVIRONMENT

Paul Hyde[1], Cristian Ulianov[2], Bogdan Pavković[3]
[1,2] NewRail Centre for Railway Research, Newcastle University, Newcastle upon Tyne, UK
[3] Institute Mihailo Pupin, Belgrade, Serbia

Abstract: A satellite positioning and communication system has been developed within the EU FP7 funded project SPARTACUS, to be applicable to different use cases where live tracking of critical assets and a detailed and accurate operational picture is essential to the operation of those assets. This paper presents the testing of the satellite tracking system in rail transport environment. The test program was designed to verify the core functionalities of the system and its performance, and also to verify that the system could be effectively customised and deployed to the real-time tracking and coordination of critical assets in railway environment. The tests were carried out in controlled conditions in a full-scale railway environment to represent an operational railway. The functionalities tested included the ability of the system to communicate the rail vehicles' positions, determined from the Global Positioning System (GPS) and inertial navigation, via terrestrial and satellite communications from a collection unit on the locomotive, and the system capability to continuously update the data in real time. Another tested feature was the ability of the system to wirelessly communicate the positions of each of the vehicles in the train, via propagation of the information between adjacent vehicles, to the communication unit on the locomotive, so that the positions of all of the tracked assets on the train could be communicated. In addition to the tracking of rail vehicles, the system communication capability, to provide rail personnel in a control centre and on the field with live updates of the vehicles' position, was also tested. The tests showed that the system customisation was effective in enabling the prototype system to be installed and operated in a controlled railway environment, and that the system is able to perform the functions of real-time tracking of monitored assets and communication of data to operational personnel.

Keywords: railway assets, testing, satellite tracking, GPS, communications.

1. Introduction

There are many potential applications within the railway industry for real-time tracking and positioning of railway assets, including the following:

- Tracking of assets for logistical purposes:
  - Freight customers; integration with business logistics systems,
  - Fleet management; locate fleet precisely without dependence on Infrastructure Manager, precisely track vehicle mileage and usage, and driver performance.
- Asset management and condition monitoring (offline CM for traceability, online with communication):
  - Rail industry - location of track/infrastructure features/defects detected by trains,
  - Freight customers - location and condition of sensitive freight; temperature alarms for perishable items, tamper alarms for valuable freight.
- Safety and Emergency intervention and location:
  - Alert assets in area of incident or hazard,
  - Locate trains reporting an incident,
  - Locate hazardous freight (possible inclusion of condition monitoring).
- Traffic management:
  - Locate trains without need for expensive and extensive lineside infrastructure,
  - Authorise train movements based on known locations and tracking of all trains: Optimise track capacity and flexibility,
  - End of Train Device to locate rear of train and ensure train integrity and track behind train clear.

A number of projects in the past have attempted to develop satellite tracking for railway industry applications. Some of the earlier of these projects (GLORIA,2002; GADEROS, 2004; LOCOPROL, 2004) demonstrated the potential uses of satellite tracking, however the performance, reliability and dependability of the positioning given by the systems developed was often insufficient, particularly for safety critical traffic management. More recently the SATLOC (2014) project has developed and tested a rail traffic management system based on satellite positioning, compatible and compliant with the requirements for traffic management; however it is too early to assess the acceptance and uptake of this system by the rail industry.
The aim of the real-time satellite tracking system which is the subject of this paper was developed in the SPARTACUS (2016) project and was not intended to provide tracking of trains for traffic management, but to provide supplementary tracking that could be used for fleet logistics and customer freight tracking, as well as providing localisation of the train in emergency situations to support the response of emergency services and the railway operator. The objective of the EU FP7 funded project SPARTACUS was to develop tracking/positioning solutions for critical asset tracking and crisis

[2] Corresponding author: cristian.ulianov@ncl.ac.uk

management; this development was divided into three application areas, with the technical solutions being relevant to each application area and customised to suit the specific needs of each. The application areas are:

- To track, trace, and localise critical transport assets especially in times of crisis and in case of major failure of existing networks,
- To track the flow of relief support goods from the sending side to the receiving/end place,
- To support and ensure the safety of first responders in crisis management operations.

This paper concerns the testing of the technical solutions customised for the first application, specifically live tracking, tracing, and localising of railway assets in real-time.
The architecture of the satellite positioning technology and communication technology used in the SPARTACUS system to provide satellite tracking is as follows:

- *Tracking Units:* Tracking units are fitted to each rail vehicle in a train (and potentially cargo units such as containers as well), these consist of as Global Navigation Satellite System (GNSS) antenna which is connected to a navigation system with inertial sensors, a miniature computer to receive the position information, a ZigBee wireless transceiver module to create a low power wireless network on the train, and a battery power source. The inertial sensors in the navigation system give the tracking unit a dead reckoning capability when GNSS signal is lost,
- *Collection Units:* The Collection Unit is fitted to the locomotive and has a ZigBee wireless transceiver module and a miniature computer to collect the position data from the Tracking Units in the network (that is, the train). The position data collected from the Tracking Units is stored and sent to the Communication Unit on the locomotive which it is hard wired to,
- *Communication Unit:* The Communication Unit transmits position data to a database to enable real-time tracking of the train. The Communication Unit consists of a computer controller linked to a terrestrial 4G phone network and via satellite communications module with antenna, a smart link selection function selects most efficient data link (terrestrial or satellite) to ensure maximum communication coverage.

The tests described in this paper fit within the overall testing and validation strategy for the whole system in its different applications. The overall strategy included a three stages testing programme, including:

- 1st stage: the testing of functions of the individual components and sub-systems,
- 2nd stage: testing functionality of the integrated systems,
- 3rd stage: applying the system to realistic use case scenarios, as well as more extended tests.

The tests described here were part of the second stage and were intended to test the functionality of the integrated positioning and communications systems to verify that the system could be deployed in a real railway environment and the GNSS derived position of the transport assets (vehicles in the train) transmitted to remote servers allowing the train to be tracked in real-time.

2. Testing of Live Tracking Title

2.1. Test Installation

The railway environment represents many challenges to a system such as developed in the SPARTACUS project, e.g., the components must be sufficiently rugged, the separation between routes is limited (compared to aircraft for example) therefore the accuracy required to distinguish between them is high, trains can pass very close or inside structures which might interfere with communication and GNSS reception, etc. In addition to these precision location and general challenges, the electronic and wireless communication components must operate in an environment containing other systems and often surrounded by large amounts of metal. To represent the conditions and challenges of a real railway environment and test the functionality of the system under realistic conditions, the tests installation of the system on a real train was carried out at the testing facilities of NewRail at Barrow Hill Railway Centre U.K. The test installation consisted of a locomotive fitted with Tracking, Collection and Communication unit, and four tracking units fitted to wagons (represented by passenger carriages), the dual fitment of one vehicle with two tracking units was considered as representing a wagon carrying a shipping container, each with their own Tracking Units communicating their positions with the wireless network.
Figures 1 and 2 show the fitting of the Tracking, Collection and Communication unit to the locomotive, the satellite communications antenna being the white dome prominent on the roof of the locomotive in the middle of Figure 1, with the GNSS antennas either side. In Figure 2 the communication unit can be seen on the cab floor configured to be installed within a strong plastic flight case for protection, the integrated Collection and Tracking unit, including miniature commuter, navigation system and ZigBee network module can be seen on the far right, for the purposes of the test the system on the locomotive was powered from a 12V truck battery contained in the clear white plastic box on the left of the figure.

Fig. 1.
Photograph of the system installation on the locomotive showing the roof mounted antennas (satellite communications antenna in the centre and GNSS antennas either side)

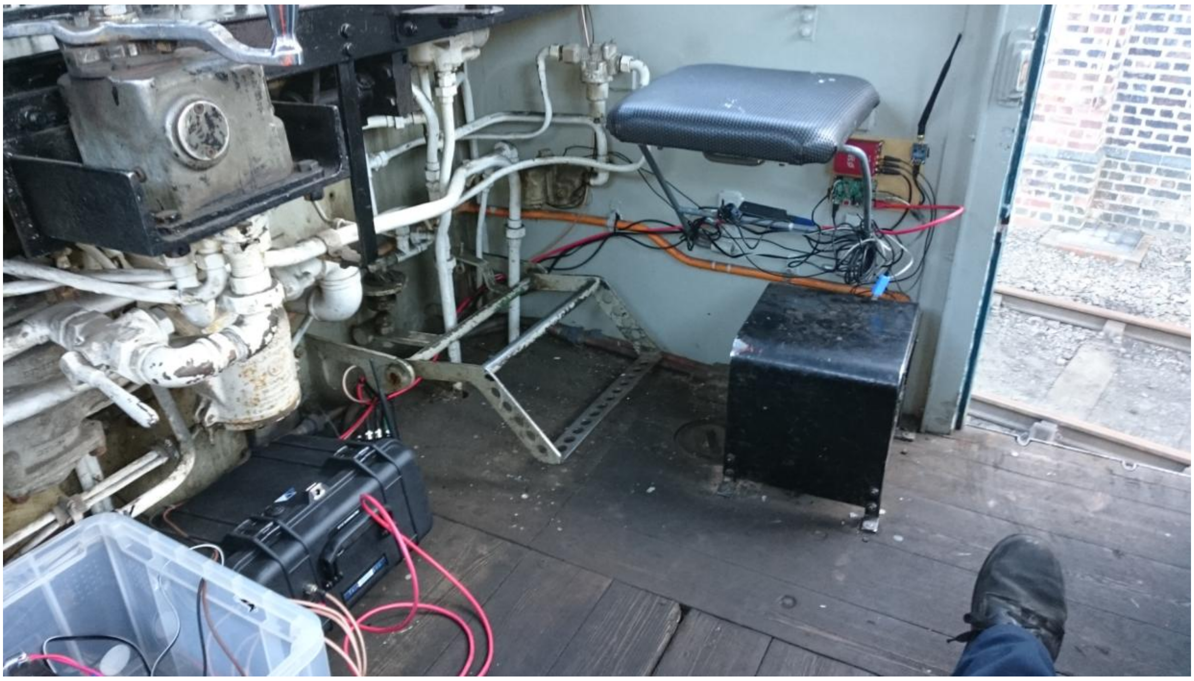


Fig. 2.
Photograph of the system installation on the locomotive showing the inside of the locomotive cab with the black communications control case under the locomotive control desk (on the left) and the tracking unit on the cab wall (on the right)

Fig. 3 shows the test train configuration with the locations of the units identified with labels, i.e., L for the Locomotive unit (as shown in **Error! Reference source not found.** and Fig. **2**.), W1, W2, and W3 relate to the position of the Tracking Units on wagons 1, 2 and 3 respectively, and C for the position of the Tracking unit fitted to wagon 3 (representing a Tracking unit fitted to a shipping container). The single GNSS antenna for the tracking units installed on the wagons (units W1, W2, W3, and C) were installed on the roof of the vehicles above the tracking units' location with a clear view of the sky.

2.2. Test Procedure

The test procedure involved initialising the tracking system by turning on the Tracking, Collecting and Communication units and driving the train along a sequence of passes on different tracks on the site. The routes consisted of a main running line from which two other routes branched off. The total distance of all of the routes travelled by the test train was 1.6km, with the longest continuous run being 1km and the maximum speed 32km/h. The test was repeated a number of times, each time the sequence of train movements being carried out twice, once with the system set to send the position data of all of the vehicles using the terrestrial mobile phone network, and once with the system set to send the position data using the satellite communication link. The selection of the communication mode was carried out manually by overriding the smart link selection feature, as the conditions were such that the terrestrial mobile phone network would always have been selected, and it was desired to test the satellite communication mode as well.

Fig. 3.
Test Train Configuration showing location of units and the fitting of a Tracking unit to a rail vehicle (see text for meaning of labels)

3. Results

The test procedure was repeated a number of times, as the initial results indicated that various refinements to the system were required; although the units had been tested under laboratory or workshop conditions, the challenges of the railway environment and operating conditions required modifications to be made in order of the system to perform as required. One issue encountered was that the initial installation position of the Tracking units on the wagons (on the floor on the centreline) the signal strength of the ZigBee wireless modules was not sufficient to provide a stable network to send position data to the Collection unit. The position of the Tracking units was changed to that one shown in Fig. 3 (on a side window with the ZigBee antenna directed outside); this enabled a stable network to be created and the positions of the tracking units to be passed to the Collection unit. Another of the issues encountered was that the navigation system within the Tracking unit required a certain direction of travel and speed threshold to be reached for the system to initialise and collect GNSS positions. Initially the results showed that the accuracy of the position was poor; for example it was observed that the position data would start off at coordinates which coincided with the route of the track on the map, but when the train moved the position trace showing the position history of the vehicle showed it moving in a path with a similar shape to rails but diverging from the mapped location of the rails. In some cases the position reported for the vehicle would be as much as 20m from the mapped location of the railway track before a GNSS fix meant the position reported by the system snapped back to one that corresponded to coordinates along the railway track. The cause of this error was identified as a combination of three factors associated with the navigation system:

- The first of these factors was that the system has a set minimum speed threshold that the train must achieve for the system to initialise correctly. The test train was not able to reach the set speed threshold quickly enough, as the locomotive did not have enough power due to the initialisation direction requiring the train to climb a steep gradient.
- The second factor was that the inertial navigation component of the system has priority over the GNSS component for updating the position, except when the GNSS signal is very good.
- The third factor was that the motion profile of a train is significantly different from those in aviation, automotive and maritime transport (which the inertial navigation component was developed for). The principal difference is that the rates of acceleration in all directions and axis of rotation is significantly less in rail transport, therefore the errors in measuring these acceleration become more significant when it comes to calculating the heading and motion of a train.

The result of the combination of these factors was that initially the inertial navigation system was not accurately measuring the motion and heading of the train, as shown by the left image in Fig. 4. The bias towards the inertial navigation system for updating the position of the train meant that GNSS position was only being used when the signal was good, even if a lower signal strength might have provided a more accurate position than the inertial navigation system. This issue was resolved satisfactorily by reconfiguring the navigation system with a lower initialisation speed threshold, so that the system was able to initialise correctly during the first movement of the train and provide accurate position data (the right image in Fig. 4). The results from the final configuration of the system showed that it was possible for the position of the locomotive and wagons to be measured accurately, and for that data to be collected and communicated to the databases (both by terrestrial and satellite communication networks), so that the position of the train could be remotely displayed on a map and recorded. Both the terrestrial mobile network and satellite communications system were able to provide a good communication pathway to transmit the collected position data to the remote servers across all of the locations and speeds the test train travelled.

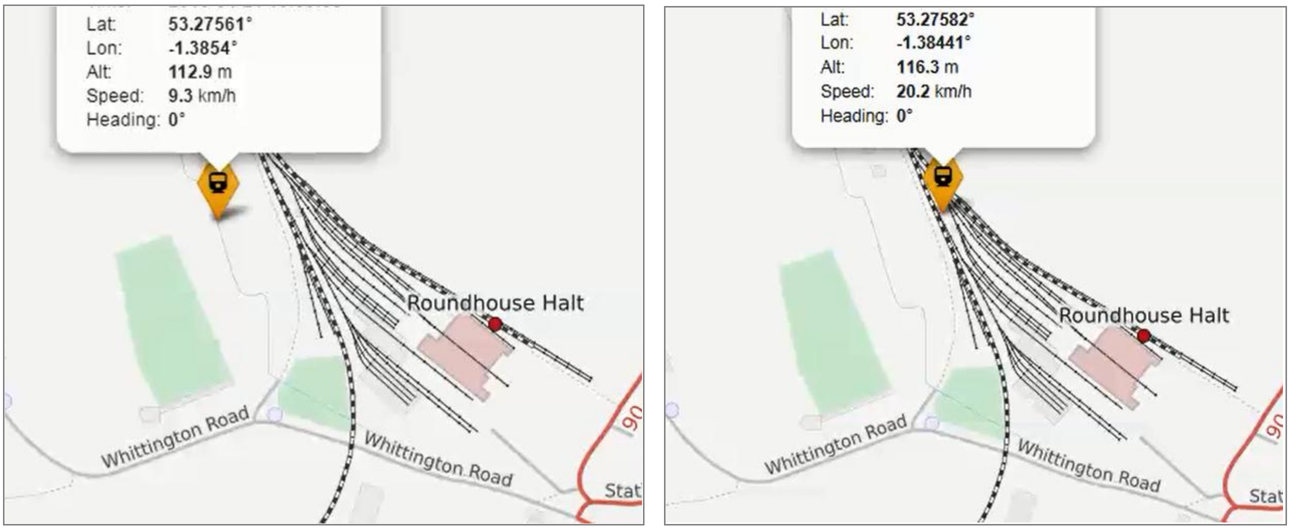


Fig. 4.
Screen shots from the asset tracking portal for visualising the live position data; the left image shows an inaccurate position from an early system configuration, and the right image shows an accurate position

The plot of the position trace recorded for the locomotive with the final system configuration for the sequence of movements along the track on site is presented in **Error! Reference source not found.**, which shows that the position of the locomotive matched very closely the mapped position of the railway tracks it was running on. The lateral positioning error for the locomotive along a portion of the route is shown in the chart in **Error! Reference source not found.**.

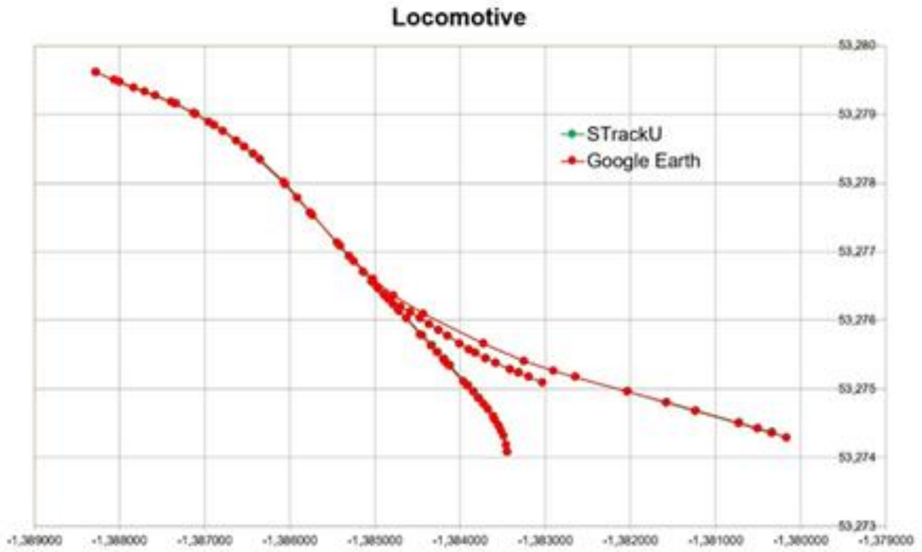


Fig. 5.
Plot of the position trace recorded for the locomotive; maximum length of the trace is approximately 1km

The positioning error statistics for the lateral positions of all of the tracking units, compared to the mapped route of the railway tracks for a complete sequence of movements along the route, are shown in **Error! Reference source not found.**.

It should be noted that the position error and position error statistics shown in **Error! Reference source not found.** and Table 1 respectively, give the accuracy of the positions relative to the route of the rail network traversed during the tests as measured from Google Earth, therefore the results are potentially affected by errors in the coordinates used for the actual position of the railway track. The results show that the accuracy of the positioning data for the final configuration of the system is accurate enough for logistics purposes and are approaching the accuracy required for operational train control. However the assessment of the lateral accuracy of the position data received has been compared to the position of the tracks shown on Google maps satellite imagery. For a more detailed and accurate assessment of the accuracy of the position data, an accurate GPS survey of the actual coordinates of the railway tracks would be required.

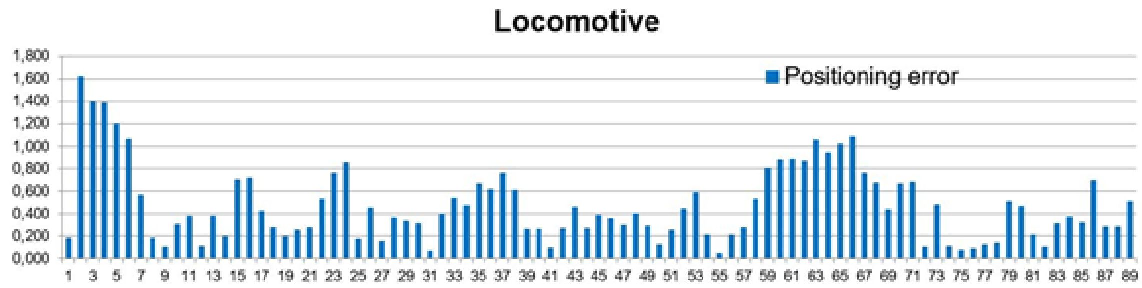


Fig. 6.
Error in the lateral position of the locomotive (measured in mm) during the movement of the train (measured in seconds)

Table 1
Positioning error, deviation from the mapped track centreline

Vehicle	Average (μ)	Standard deviation (σ)	Maximum
Locomotive (L)	0.469m	0.334m	1.263m
Wagon 1 (W1)	1.170m	0.566m	2.864m
Wagon 2 (W2)	1.366m	0.847m	4.196m
Wagon 3 (W3)	1.425m	0.722m	3.446m
Container (C)	0.803m	0.511m	2.009m

4. Conclusions

Installation of a railway vehicle positioning and position communication system was achieved and successfully tested in a full-scale railway environment. After adaption of the system to railway conditions and environmental characteristics, and refinement of the system hardware and software configuration it was shown that the system was able to communicate the position of all of the vehicles in the train to a remote location in near real-time. The accuracy of the positioning data was demonstrated to be sufficient for the overall aims of the project, which is to achieve critical asset tracking for logistical purposes in a variety of applications. However, more accurate reference position of the rail vehicles and tracks would be required to fully assess the accuracy of the positioning system.
The system was installed in conditions representative of an operational railway environment. This indicates that similar results could be expected if the system was applied to a national railway network, although a series of trials would be required to verify this and identify any additional issues. Therefore, the tests showed that the SPARTACUS system is potentially capable of providing real time tracking data for railway vehicles and freight assets in a railway environment, which could be utilised by train operators for logistical purposes and providing rail freight customer's real-time tracking of their goods, allowing them thus to be integrated into their logistics systems.

Acknowledgements

The development of the systems presented within this paper and the testing program were funded and carried out as part of the EU FP7 project SPARTACUS. More information, including the public reports and deliverables, can be found on the project website: http://www.spartacus-project.eu/ .

References

GLORIA 2002. GLORIA-GNSS & LORAN-C in Road and Rail Applications, project summary. Available from Internet: <http:// http://www.transport-research.info/project/gnss-loran-c-road-and-rail-applications>.
GADEROS 2004. GADEROS-Galileo Demonstrator for Railway Operation System, project summary. Available from Internet: <http://www.transport-research.info/project/galileo-demonstrator-railway-operation-system>.
LOCOPROL 2004. LOCOPROL-Low Cost Satellite Based Train Location System for Signalling and Train Protection for Low Density Railway Lines project summary. Available from Internet: <http://www.transport-research.info/project/low-cost-satellite-based-train-location-system-signalling-and-train-protection-low-density>.
SATLOC 2014. SATLOC-Satellite based operation and management of local low traffic lines project summary. Available from Internet: <http://satloc.uic.org/Project-summary>.
SPARTACUS 2016. Satellite Based Asset Tracking for Supporting Emergency Management in Crisis Operations project summary. Available from Internet: < http://cordis.europa.eu/project/rcn/110848_en.html>.

SESSION 4: INLAND WATERWAYS TRAFFIC AND TRANSPORT RESEARCH

THE RECENT DYNAMICS OF THE NAVIGATION AND MAIN HARBOR OPERATIONS IN THE AREA OF THE MARITIME DANUBE

Carmen Gasparotti[1], Alina Modiga[2], Leonard Domnisoru[3], Eugen Rusu[4]
[1,2,3] *"Dunarea de Jos" Faculty of Naval Architecture, Dunarea de Jos University of Galati, Galati, Romania*
[4] *"Dunarea de Jos" Department of Mechanical Engineering, Dunarea de Jos University of Galati, Galati, Romania*

Abstract: The Rhine-Main-Danube navigation system, known also as the Seventh Pan-European transportation corridor, represents the main inland navigable waterway in Europe that crosses the entire continent and links Sulina at the Black Sea with Rotterdam at the North Sea. Since the river transportation still represents the cheapest way for the commercial traffic, the importance of this waterway is expected to be enhanced in the near future. In this context, the target of the present work is the maritime sector of the Lower Danube, which links the Romanian harbors between Sulina and Braila. This work is mainly focused on the cargo traffic in the low Danube region. The most important ports in this area are Galati, Braila and Tulcea in Romania, Reni and Izmail in Ukraine and Giurgiulesti in the Republic of Moldova. The Romanian Ports on the Maritime Danube, Galati, Braila and Tulcea have a long lasting tradition as inland ports, which offer access to both the Black Sea and the North Sea, through the Rhine-Main-Danube navigation system. The present work gives some relevant insights concerning the navigation and the possible sources of hazards in the maritime sector of the Danube, where usually navigate both sea and river ships.

Keywords: maritime Danube, river traffic, harbor operations, harbor dynamics, navigation risks.

1. Introduction

Danube River is an important waterway that runs over 2400 km from Bavaria to the Danube Delta, passing through eleven countries. It is a part of the Rhine-Main-Danube waterway that links the North Sea and Black Sea, representing the VII Pan-European transportation multimodal corridor, being also a link to other corridors. Danube represents one of the most advantageous transport routes in Romania, due to the low costs and high volume of cargo transported (Rusu, 2010). The development of the VII Pan ‐ European Corridor, Danube ‐ Rhine ‐ Main regions, allows to all the states in Europe a connection with the sea harbors (Zanopol et al, 2014).

An important role for the navigation on the Danube has the Danube-Black Sea Channel. This ensures a direct link between the main harbor of Romania, Constanta, at the Black Sea, and the Danube, thus avoiding the difficult navigation in the Danube Delta. The Danube-Black Sea Channel splits in two. So, the main channel goes to the south towards the harbors Constanta and Agigea and the North Channel reaches the Black Sea at the Midia harbor. The connection of the Danube-Black Sea Channel to Europe's inland network of channels, including Rhine-Main-Danube, reduces the distances between Rotterdam and Constanta, from 6000 km on the old maritime line to 3000 km (Sobaru et al, 1998). The Danube - Black Sea Channel has been designed to facilitate the transit of long convoys, consisting of 6 barges, up to 3000 tons each. The ships up to 5,000 tons, which comply with the maximum dimension of channel, can navigate on the channel (Gasparotti and Rusu, 2014).

Much of the total tonnage of the cargo represents the international traffic. So, the Danube - Black Sea Channel and the Danube River, represents international waterways, which provides to the inland countries access worldwide (Gasparotti et al, 2013). The peak year for the traffic on the Danube-Black Sea Channel was in 2005, during which there were operated over 15 million tons, and also in 2013. The Danube operates 9% of total freight transport in Romania (National Institute of Statistics, 2011), from the total of cargo tons. The maritime sector of the Danube is for the river and sea shipping, extending between Braila and Sulina harbors, with a total of 175 km, from which the Sulina channel has a length of 62.6 km. The Sulina channel has the following ships' maximum dimension: 200 m length, 28 m breadth, 7.32 m draught, and a capacity up to 40,000 dwt. At the entrance of Sulina channel the water depth is restricted to 7-9 m, thus requiring continuous dragging operations to keep the channel open.

The advantages of the river transport compared to other modes of transport, the demand for the development of the link between river and sea harbors has raised the question of finding ways of connecting the Danube River with the sea-harbors in the region (Ivan et al, 2012). The features of the Danube River waterway, the distances between the main harbors in the region and the characteristics of the Danube harbors, are the basis for the implementation of inland and maritime shipping along the Pan-European corridors. The main harbors located on the Danube allow the shipping extension to the Black Sea region, as follows:

- Braila, Galati, Sulina – to Moldavia, South of Ukraine, South of Russia and Georgia,
- Constanta Harbor – to Turkey, Georgia, Greece, and other countries through the ocean,
- River Danube harbors (Giurgiu, Oltenita, Turnu Magurele, Drobeta Turnu Severin) – to Serbia, Bulgaria, Greece, Turkey.

The following waterway sections can be found on the Ukrainian Danube (Figure 1):

- Maritime Danube Reni harbor (km 172) – Black Sea,
- Reni harbor – Izmail harbor,
- Chilia Channel,

[2] Corresponding author: alina.modiga@ugal.ro

- Danube – Black Sea Bystroe Channel.

The Izmail harbor is located on the International Transport Corridor No. 7 (Doubrovsky, 2005). From this perspective, the present work is mainly focused on the cargo traffic in the low Danube region together with the main harbors operations. In order to obtain a complete picture of the river shipping systems that can be used on the Danube - Black Sea and the Danube - Rhine – Main waterways, this work contains the main harbors of the Lower Danube region, harbor operations and the dynamic of harbor traffic.

2. Main harbors in the maritime Danube region and critical navigation conditions

The maritime sector of the Danube starts from Sulina to the Braila harbor, with a minimum depth of the waterway 7.2 m, required by the maritime ships. The maritime Danube includes the Romanian harbors Galati, Braila and Tulcea. The fourth harbor is Giurgiulesti, located at mile 72.2 on the Danube, which operates since the 26-th October 2006.
The Romanian harbors on the maritime Danube have constantly increased their maritime ships traffic. This requires constant dragging operations to keep the Sulina Channel open to the maritime ships (Rusu and Guedes Soares, 2011). Total cargo traffic between Romania and Danube countries is estimated at 20666 million tons per year, of which the river traffic is of 13896 million tons per year.

2.1 Main harbors in the maritime Danube

The harbors located in the maritime Danube region are shown in Figure 1.

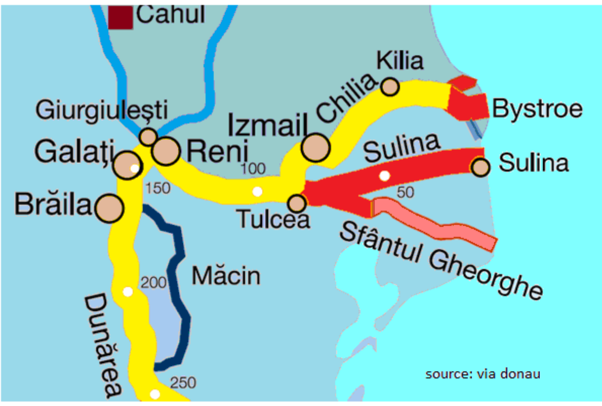


Fig. 1.
The maritime harbors on the lower Danube
Source: (Maritime Danube ports - maritimedays.odessa, 2013)

Galati Harbor Galati Harbor is the largest Danube maritime harbor, located on the left bank of the Danube River, at the eastern border of the European Union with the Republic of Moldova and the Ukraine. Galati is the second largest maritime harbor granting access to the Black Sea, with a rail link to inland countries from the Central Europe (Rusu et al, 2014).
Galati harbor ensures the cargo trans-shipment from barges to maritime ships, for the other Black Sea harbors. The harbor has four terminals: Docks Terminal for general cargo and containers, New Basin Terminal for general cargo, Oil Terminal for oil products and Mineral Terminal. Galati harbor provides the trans-shipment services for all modes of transport and temporary storage, customs clearance, free zone regime, service and ship repairs, services for the collection of waste from ships. There is the only harbor that can operate the direct trans-shipments from the maritime and river ships to the rail system. The technical facilities of Galati harbor include 56 berths, 31 gantry cranes, 10 truck cranes and 9 floating cranes, a forklift and conveyor belts for the transportation of great quantities of coal and iron ore, and also cargo storage on open platforms and closed stores. The surface of the harbor enclosure is of 864131 m^2, from which the open storage area is of 538320 m^2 and the covered storage area is of 7200 m^2. Galati Harbor has two parts: minerals harbor and commercial harbor. The Minerals harbor is operates bulk cargos and also steel rolled products. It has a quay of 1700 m length with 26 shore cranes and 18 shore cranes of 16 t. There are also two conveyors for ore and limestone on the quay. There is an anchorage area at the Minerals harbor at the right side of the Danube River, for maritime ships and barges. The maximum capacity of the ships that can operate in this harbor is of 25000 dwt, with an average depth at quay of about 9 m and the minimum depth of about 7.3 m.
The Commercial harbor is composed from several zones, as follows:

- The old docks, for maritime ships, placed upstream,
- New basin, for maritime ships, placed upstream,
- The ore and steel products zone, for maritime ships,
- The shipyard “damen” galati,

- The road for transit operations,
- The anchorage zone for the maritime ships downstream.

The river traffic of containerized cargo at Galati harbor is underdeveloped, with maximum capacity of 30000 TEU/year and a berthing front for the maritime ships with 136.85 m length. In Galati harbor can operate specialized ships, specialized containerships, semi-containerships, river adapted ships (General Transport Master Plan of Romania - part II, 2014).

Braila Harbor Braila Harbor is a river maritime harbor, situated on the left border of the Danube, between Km 168+300 and Km 170+875. The anchorage zones are established between Km 167 - 168 for the maritime ships and at Km 175 m for river ships. The harbor sectors are the following:

- Old Harbor (Km 169.8 – Km 170.875) has 8 berths which are equipped with floating pontoons, used for passengers, fresh water supply, and general cargo operation with floating cranes.
- Docks Harbor has 496 m of pier on Danube front and 1568 m of pier at basin. The main facilities are grains, silo, bulk and general cargos operations by shore cranes.
- Down river of Docks Basin has a 396 m of pier at Danube water-front for passenger's traffic.

The total surface of the harbor is of 398630 m^2, with an open storage area of 250350 m^2 and a covered storage area of 10804 m^2. Braila harbor has 12 truck cranes (max. 16 t), 8 auto-cranes (max. 25 t), 2 floating cranes (max. 30 t), 5 forklifts, conveyors and pneumatic equipment suitable for handling grain and 25 berths.

Braila harbor has a maximum theoretical capacity of 3.1 million tons per year (General Transport Master Plan of Romania - part II, 2014).

Tulcea Harbor Tulcea is a harbor with 41 berths, of which 5 berths are dedicated to the cargos traffic, 8 gantry cranes (max. 16 t), and a total surface of 82762 m^2 with open storing area of 70000 m^2. The harbor is the gateway to the Danube Delta and has a specific sector for passenger ships. The harbor handles mineral products, quarry extracted, aggregates, gypsum, slag, salt, supplying the materials for the construction sector. The harbor facilities are organized around the quarry extraction and loading materials, open platforms for goods storage waste reception from the ships, maintenance of the ships, harbor equipment's for the ships' operations. Tulcea harbor has not terminals for cereals operations. The Tulcea passenger terminal can handle international and river traffic. At a short distance is also the Tulcea Industrial Harbor for the local metal processing factories. The main activities are the operations of various raw materials: bauxite, iron, ore, lime, ferrous alloys, from the river and maritime ships (General Transport Master Plan of Romania - part II, 2014).

Reni Harbor Reni and Izmail harbors are located close to the Galati harbor, at only 23.5 km and 89.1 km. Reni harbor is located at the borders of Ukraine, Romania and Moldavia. Four transport corridors are intersecting: Europe – Asia, Black Sea and Cretan no. 7 and 9, is being a sea and river harbor. Reni harbor covers 940000 m^2, from which the main operation basin area has 440000 m^2. The water depth in the operation area varies from 2 m up to 25 m. Reni harbor has 6 anchorages points, from which 3 of them are for maritime ships and 3 for barges. Reni commercial sea harbor is a multipurpose transport hub in southern Ukraine. Reni harbor has 30 specialized berths which handle practically with all kinds of cargos, bulk dry and liquid, heavy-weight, containers. The harbor facilities are: 1 bridge crane with a lifting capacity of 250 t, 11 fork-lift trucks, 2 lift truck, 2 bucket loader, 1 harbor tractor, 1 crane Kato, floating cranes. The annual capacity of the harbor is about of 14.5 million t. The berthing line extends to 3927 m with the water depths of about 12 m. The port has specialized terminals for oil handling and ferry. Reni harbor has three specialization cargo areas. First cargo area has a total berthing length of 960 m with an annual capacity of 1 million t, capable to operate ships up to 10000 dwt. The second cargo area has a total length of the berths of 1960 m and an open zone that covers 62737 m^2. The annual capacity average is of 2.5 million t. The maximum operation draught is up to 7 m, for ships up to 20000 dwt. The third cargo area is specialized in handling of bulk cargoes, ore, pellets, coal, iron ore sinter, coke, with annual capacity of 2 million t. The total length of the berths is of 565 m and the open zone that covers 61650 m^2, with ships up to 3000 dwt. The oil harbor is specialized in crude oil and petroleum products with a total berthing line of 258 m, for ships of 20000 dwt. The annual capacity is up to 1.8 million t of oil and petroleum products, and 200000 t of liquefied gas (Reni Sea Port, 2016).

Izmail Harbor Izmail harbor is situated at the Kaliya mouth of the Danube River, at 93 km from the Black Sea, being at the intersection of trade routes between the countries of Central and Northern Europe with those of the Black and Mediterranean Seas. The harbor area is on the Kiliya mouth of the Danube River, from 78 up to 96 km, up to the conventional line of the Ukrainian border on Danube. Izmail harbor can operate ships of maximum 150 m length, width up to 30 m and draught up to 7 m. The harbor has modern facilities and equipment for operation of bulk cargo, and containers. The harbor has 24 berths with depths from 3.5 m to 7.5 m, with three cargo terminals, 8 warehouses with a total area of 19700 m^2, 3 floating Ganz cranes (16 t) and 100 truck lifts (1.5 - 25 t). There are also 6 automobile and caterpillar cranes of 6.3- 50 t capacity. The open cargo storage area is of 201100 m^2, with 53 gantry cranes (40 t). The first terminal has 8 berths, operating packed cargoes, equipment, agricultural machines, metals, and grains. The total operation capacity is 1.2 million t per year. The second terminal has 4 berths, operating bulk cargos and containers. The operation capacity is up to 5.4 million t per year. The third terminal has 7 berths, operating bulk and general cargos (Izmail Sea Port, 2016).

Giurgiulesti Harbor Giurgiulesti harbor has river-sea operations, located at the 133 km on the Danube, being the only Republic of Moldova harbor. The harbor has intermodal facilities for containers operations and terminals for oil products, grains and passenger transport. The terminal for oil products has one berth, an oil base with 8 reservoirs for

63000 m^3 storage of petroleum products, operation capacity of over one million tons per year and facilities for railway cisterns handling. The grain terminal has a storage capacity of 50000 tons and the operation capacity of 3000 tons per day, for ships up to 7000 dwt. The vegetable oil terminal has a storage capacity of 6000 tons, for ships up to 10000 dwt. The bulk terminal is located on the banks of the Prut and has an area of 40000 m^2, for petroleum coke, crushed stone and quarry products. The container and general cargo terminal has an open storage area of 20000 m^2, with cranes with maximum lifting capacity of 70 t (Giurgiulesti International Free Port, 2016).

2.2. Auxiliary harbors and related activities

Besides the activities directly related to the shipping, as cargo loading-discharging, stowage-lashing, storage on platforms, in the harbors there are also a series of auxiliary activities (National Company the Administration of Maritime Danube Ports, 2016). The auxiliary harbor activities include:

- Maintenance of the technical characteristics of the water transport infrastructure,
- Land and floating navigation signals,
- Maintenance dredging to ensure the navigation depths in harbors and waterways,
- Collecting the residuals, wastewater and garbage from ships,
- Salvage and refloating of the ships.

The related activities for harbors as support for the main activities are:

- Cargo traffic monitoring in the harbor, issuing the cargo shipping operations database,
- Approval of the studies and projects for the development of water transport infrastructure,
- Establishing of the fees for the harbor service,
- Development of the it harbor services.

2.3. Issues identified in harbors

The analysis on short and long term of the activities and the facilities of the maritime-river harbors on the Danube from Romania have revealed some issues that are affecting the efficiency of the harbor activity: old or undeveloped infrastructure, poor connectivity, the inability to operate new cargo types, lack of intermodal functionality, capacity deficit (Table 1) (General Transport Master Plan of Romania - part II, 2014).

Table 1
Identified problems in Romanian harbors on the lower Danube

Harbor	Identified problems				
	Old or undeveloped infrastructure	Poor connectivity	Inability to operate new cargo types	Lack of intermodal functionality	Capacity deficit
Tulcea		x	x		x
Galati	x	x	x	x	x
Braila	x	x			

Source: (General Transport Master Plan of Romania - part II, 2014)

Galati harbor has an old infrastructure in some parts over 50 years. In addition, this infrastructure was designed for the requirements of Galati steel industry, which in the last decade has significant decreased. The harbor has a poor connectivity, which combined with the old infrastructure, cannot have a proper bulk cargo and palletized cargo terminals. This will allow increasing the operation capacity of modern cargo types and the harbor international integration (Gaparotti, 2009).
Braila harbor has an old infrastructure, with outdated berths and bad connections with other transport ways. The harbor modernization will allow the increase of the cargo capacity operation.
Tulcea harbor has a reduced capacity of operating the cereals, so that the general cargo terminal must be upgraded grain handling. This will increase the harbor capacity and new cargos operation.

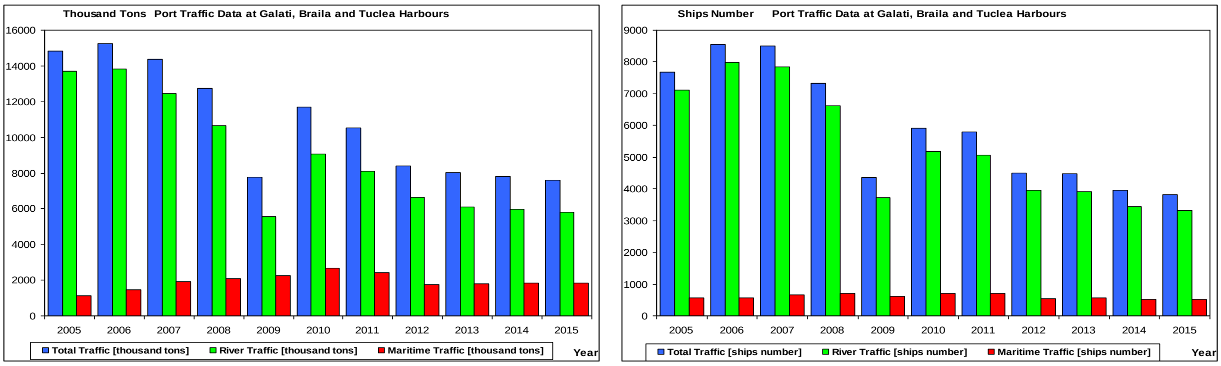
2.4. Critical conditions for navigation

The navigation on the maritime Danube has several difficulties due to unfavorable meteorological and hydrological conditions. From the meteorological point of view, the winds have a dominant influence, with high intensity in autumn and winter, generating often storms. In March the haze occurs, cloudiness increases, with drizzle and even sudden decrease of the temperature down to -10^0 C (Gasparotti and Rusu, 2012). From the hydrological point of view, the difficulties of navigation are determined by the presence in some areas of the Danube of a narrow waterway, restrictions due to, riverbed deposition of silt, strong currents and pronounced curves with small radius of the waterway. The traffic is most difficult in the Tulcea elbow, at the entrance of Sulina channel, but also in other parts of the maritime Danube.

Due to the environmental conditions for the ships' safety there are imposed several navigation restrictions (Gasparotti et al, 2014).

3. Dynamics of the cargo traffic in the main harbors

The traffic system in the Danube maritime harbors is a part of the European traffic system, ensuring the link of Romania to other European countries (Omer, 2015). The cargo traffic in the three sea-river harbors, Galati, Braila and Tulcea, is shown in Figure 2.



a b

Fig. 2.
Port traffic data at Galati, Braila and Tulcea harbors, a-thousand tons and b-ships number
Source: (National Company the Administration of Maritime Danube Ports, 2016)

From Figure 2 results that the traffic through these harbors has declined continuously over the last decade, 2005-2015, particularly in 2009, only 40.5% compared to 2005. Some increase has been recorded in 2010-2011 and after the traffic has been reduced to similar level of 2009. The significant reduction of the marine traffic in the Danube harbors is due to the financial and economic crisis that has also involved Romanian starting 2008. The river traffic share in the total cargo transport is higher than the maritime one. The cargo traffic with river ships is going on the entire length of the Rhine-Main-Danube Channels, from Sulina to Rotterdam. The cargo traffic with maritime ships is going on from Sulina (km 0) to the Braila harbor (km 175). Galati, Braila and Tulcea harbors have a diversified cargo traffic, being composed of raw materials products (career and gravel, gypsum, clay, salt), ferrous and non-ferrous ores, rolled, cereals, food, tobacco, timber, construction materials, oil, solid fuels (coal, coke) (General Transport Master Plan of Romania - part II, 2014). In 2011 the main types of cargos operated in the three harbors were: iron and ores for Galati, cereals for Braila and ores for Tulcea (fig. 3).

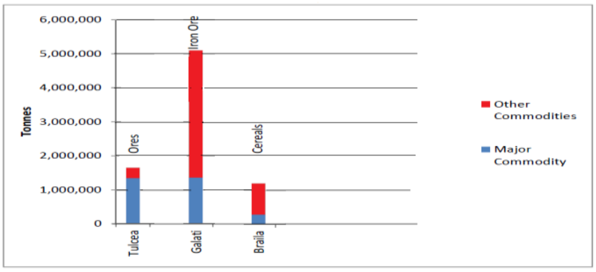


Fig. 3.
Tonnes handled by Romania's maritime harbors from the Danube in 2011
Source: (*General Transport Master Plan of Romania - part II, 2014*)

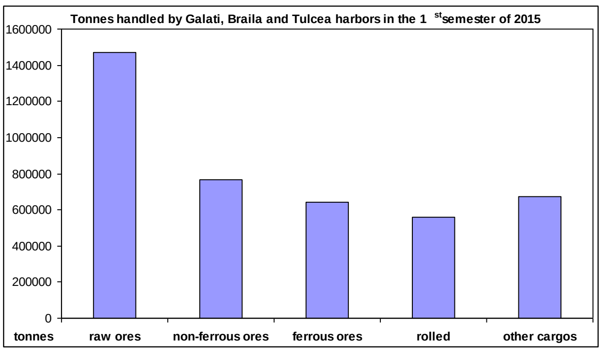
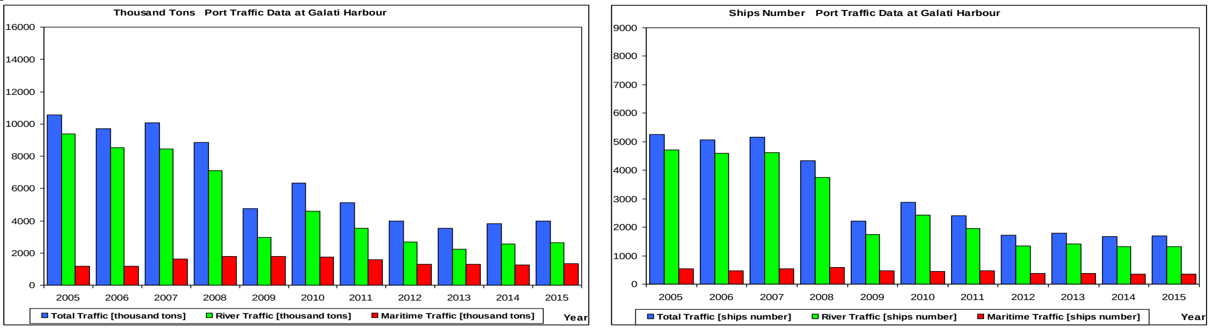


Fig. 4.
Tonnes of cargo handled by Galati, Braila and Tulcea harbors in the first semester of 2015
Source: (*General Transport Master Plan of Romania - part II, 2014*)

In the first half of 2015, the total traffic by groups of cargos reveals that mineral products gross (career, gravel, gypsum, clay, salt) were in the largest amount followed by non-ferrous ores, iron ore and rolled (fig. 4). In the Galati harbor (fig. 5) the total and inland traffic has a down-trend, reaching the minimum in 2009 and then, after a slight increase in 2010-2011, decreases to values under 2009 reaching 37.65% for the total traffic and 27.9% for river traffic taking as reference year 2005.



a b

Fig. 5.
Port traffic data at Galati harbor, a-thousand tons and b-ships number
Source: (National Company the Administration of Maritime Danube Ports, 2016)

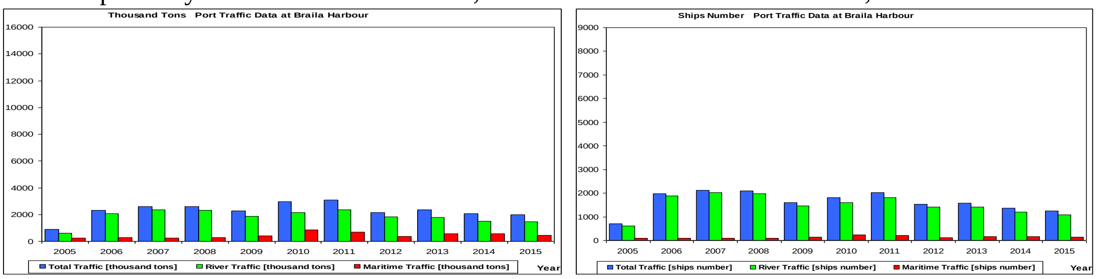
The maritime traffic has had an up-trend in the period 2005-2009, when it has increased by 54.8% in 2009 taking as reference year 2005, and after 2009 it has had a down-trend, in 2009 the traffic being higher by 37.7%, and in 2011 by 21.9% taking as reference year 2015. The number of ships operating in Galati harbor has continuously decreased for both river and the maritime traffic. The major part of the traffic share represents the bulk cargo (iron ore, coal, cereals, scrap metal, building materials), the general and standardized cargos traffic being very reduced. The decrease of the traffic in the Galati harbor is mainly due to the decrease of the coal and steel handled for the local steel industry that is in decline. The recorded operations in Galati harbor in 2011 and the forecasted one for 2020 and 2030 are presented in Table 2.

Table 2
The recorded and forecasted operations in Galati harbor having as reference year 2005

Terminal	**2011**	**Forecasted**	
		2020	**2030**
General cargos	41.83%	45.39%	49.49%
Bulk cargos	100.79%	109.37%	119.26%
Containers	-	-	-
Petroleum products	-	-	-
Cereals	30.21%	32.78%	35.74%
Cement	-	-	
Coal	7.22%	7.84%	8.54%
Steel	-	-	-
Other	0.96%	1.90%	2.62%

Source: (General Transport Master Plan of Romania - part II, 2014)

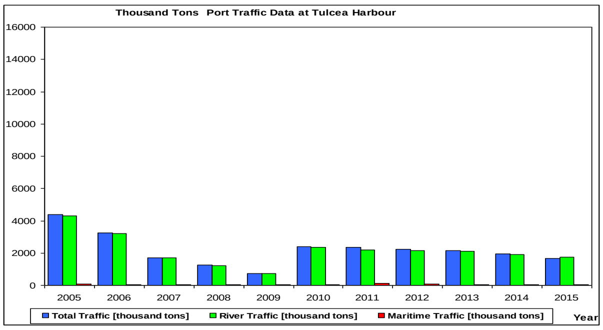
Table 2 shows that the bulk cargo terminal operates at full capacity, the general goods operates at almost half capacity, the cereals terminal operates at a third capacity, while the other terminals operate at a very small volumes and the prognosis keeps this trend. The cargo traffic at the Braila harbor (figure 6) had an up-trend in 2005-2011, for both river and maritime traffic as tonnage and number of ships, reaching a maximum for the total and the river tonnage in 2011, of 251% respectively 281% referenced to 2005, and for the maritime traffic in 2010, of 232% referenced to 2005.



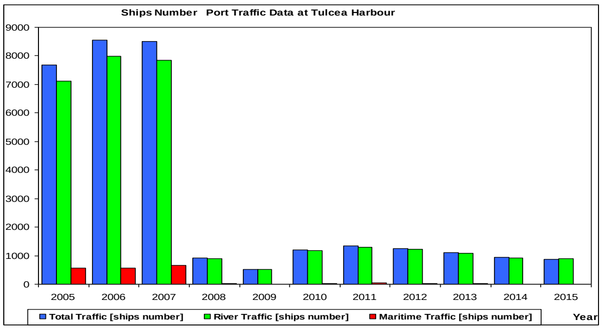
a b

Fig. 6.
Port traffic data at braila harbor, a-thousand tons and b-ships number
Source: (National Company the Administration of Maritime Danube Ports, 2016)

The main cargos traffic in the Braila harbor is mineral products, wood products and chemical fertilizers. In Tulcea harbor, the cargo traffic is lower than in Galati and Braila harbors. There was a down-trend in 2005-2015 (figure 7), the minimum value being reached in 2009, of 16.85% referenced to 2005, and after that there was recorded a significant increase, especially in 2010-2013, both as tonnage and the number of ships.



a



b

Fig. 7.
Port traffic data at Tulcea harbor a-thousand tons and b-ships number
Source: (National Company the Administration of Maritime Danube Ports, Galati, 2016)

The recorded operations in Tulcea harbor in 2011 and the forecasted one for 2020 and 2030 are presented in Table 3.

Table 3
The recorded and forecasted operations in Tulcea harbor having as reference year 2005

Terminal	2011	Forecasted	
		2020	2030
General cargos	7,97%	11,00%	11,36%
Bulk cargos	100,60%	117,47%	113,69%
Containers	-	-	-
Petroleum products	-	-	-
Cereals	1,53%	1,79%	1,73%
Cement	-	-	-
Coal	-	-	-
Steel	-	-	-
Other	-	-	-

Source: (General Transport Master Plan of Romania - part II, 2014)

Table 3 shows that in 2011 the terminal for bulk cargo has been used at full capacity and for 2020 and 2030 is forecasted a growing demand over the available capacity. The general cargos and cereals terminals had a reduced activity and is forecasted to keep this trend (General Transport Master Plan of Romania - part II, 2014).

4. Conclusions

Danube River is an important waterway of Europe, being part of the Rhine-Main-Danube multimodal transportation corridor that links Sulina, at the Black Sea, with Rotterdam, at the North Sea. The maritime Danube presents a number of restrictions due to the unfavorable meteorological and hydrological conditions as wind, fog, variable water depth and breadth, strong currents strong, tight curves.

The maritime-river harbors in the Lower Danube zone are: Galati, Braila and Tulcea from Romania, Reni and Izmail from Ukraine and Giurgiulesti from the Republic of Moldova. As the present work shows, it is necessary to develop consistent investment projects for the modernization of the harbors infrastructure and of specialized terminals, in order to increase the operational capacity, new cargos to be handled and their integration into the international cargos traffic.

The cargo traffic in Galati and Tulcea harbors had a down-trend in 2005-2015. On the other hand, in Braila harbor both river and maritime cargo traffic had an up-trend in the same period. The recorded operations are maximum for bulk cargos, relatively low for the general cargos and cereals and very low for other type of cargos in the Galati harbor. In the case of Tulcea harbor the recorded operations are maximum for bulk cargos and very low for the cereals and general cargos.

Finally, it has to be highlighted that the volume of cargos traffic at the river-maritime Danube harbors has important values, those harbors playing a significant role for the European transport. Moreover, in the future it is possible to develop this cargo traffic and the quality of services by proper investments into the harbor facilities.

References

Doubrovsky, M. 2005. Ukrainian and Russian waterways and the development of European transport corridors, European Transport\Trasporti Europei n. 30 (2005): 14-36. Available from Internet: < https://www.openstarts.units.it/>.

Gasparotti, C.; Rusu, E. 2012. Methods for the risk assessment in maritime transportation in the Black Sea basin. Protection and Sustainable Management of the Black Sea Ecosystem, *Journal of Environmental Protection and Ecology,* 13(3A): 1751-1759.

Gasparotti, C.; Domnisoru, L.; Rusu, E. 2014. Scenarios for the navigation routes in the Black Sea considering the seakeeping safety criteria. In *Proceedings of the 14th International Multidisciplinary Scientific GeoConference, SGEM 2014*, 17-26.

Gasparotti, C.; Rusu, E.; Dragomir, S. 2013. The impact of anthropogenic activities on the water quality in the Danube river basin. In *Proceedings of the 13th International Multidisciplinary Scientific GeoConference SGEM 2013,* 987-994.

Gasparotti, C.; Rusu, L. 2014. Prediction of the dynamic responses for two containerships operating in the Black Sea, *Journal of Naval Architecture and Marine Engineering*, 11(1): 55-68.

Gasparotti, C. 2009. The internal and external environment analysis of Romanian naval industry with SWOT model, *Review of Management and Marketing*, 4(3): 97-110.

General Transport Master Plan of Romania - part II, 2014. Available from internet: Available from Internet: <http://www.adrse.ro>.

Giurgiulesti International Free Port, 2016. Available from Internet: <http://www.gifp.md/>.

Ivan, A.; Gasparotti, C.; Rusu, E. 2012. Influence of the interactions between waves and currents on the navigation at the entrance of the Danube delta. Protection and Sustainable Management of the Black Sea Ecosystem, *Journal of Environmental Protection and Ecology*, 13(3A): 1673-1682.

Izmail Sea Port, 2016. Available from internet: <http://www.sifservice.com>.

Maritime Danube ports - maritimedays.odessa, 2013. Available from internet: <https://www.google.ro/#q=A+review+of+Maritime+Danube+ports+with+specific+reference+to+Ukrainian+port+reform+Edgar+Martin+pptx>.

National Company the Administration of Maritime Danube Ports, Galati. 2016. Available from internet: <http://www.romanian-ports.ro/html/servicii_portuare.html>.

National Institute of Statistics (INSSE), 2011. Available from internet: <http://www.insse.ro/cms/files/publicatii/Romania_in%20cifre%202011.pdf>.

Omer, I.; Mateescu, R.; Rusu, L.; Niculescu, D.; Vlasceanu, E. 2015. Coastal works extensions on the Romanian touristic littoral, its ecological impacts on the nearshore bathing areas, *Journal of Environmental Protection and Ecology*, 16(2): 424-433.

Reni Sea Port, 2016. Available from internet: <http://www.sifservice.com/index.php/en/directory/ports-ukraine/sea-ports/item/147-reni-sea-port>.

Rusu, E.; Guedes Soares, C. 2011. Wave modeling at the entrance of ports, *Ocean Engineering*, 38(17-18): 2089-2109.

Rusu, E. 2010. Modeling of wave-current interactions at the Danube's mouths, *Journal of Marine Science and Technology*, 15(2): 143-159.

Rusu, L.; Butunoiu, D.; Rusu, E. 2014. Analysis of the extreme storm events in the Black Sea considering the results of a ten-year wave hindcast, *Journal of Environmental Protection and Ecology*,15(2): 445-454.

Sobaru, Al.; Năstase, G.; Avădanei, C. 1998. *The Danube-Main-Rhin waterway artery. European strategies for the horizon 2020*, Economică Publishing House, Bucharest, Romania.

Zanopol, A.; Onea, F.; Rusu, E. 2014. Longshore curents evaluation along the Romanian Black Sea coast. In *Proceedings of the 14th International Multidisciplinary Scientific GeoConference, SGEM 2014,* 637-644.

EVALUATION OF INFLUENCES OF WIND INDUCED FORCES AND MOMENTS ON THE RESISTANCE AND MANEUVRABILITY OF RIVER SHIPS

Liviu Crudu[1,2], Dan C. Obreja[1], Sandita Pacuraru[1]
[1] *Faculty of Naval Architecture, University "Dunarea de Jos" of Galati, Romania*
[2] *NASDIS srl, Galati, Romania*

Abstract: As compared to seagoing ships the influence of the aerodynamic loads on the river ships has to be taken into account in a different manner due to the possible instant modification of both speed and wind direction. The evaluations of the hydro-aerodynamic loads for a range of ship speeds, heading angles and wind speeds and their effects have been carried out for two types of river ships: a Port Container 156 TEU and a Chemical Tanker of 5300 m^3. Based on the calculations, comparative numerical examples are presented.

Keywords: ship resistance, wind forces and moments, maneuverability of river ships, aerodynamic resistance.

1. Introduction

The possible instant modification of both speed and wind direction could lead to important effects on ship hydro-aerodynamic resistance and course keeping ability taking into account the appearances of different rapid combinations between ship speed, wind direction and speed as well as ship heading. The effects of such combination are even more evident when different restrictions like shallow water, limited breadth of channels, geometry of river courses, limitation of ship speed, etc., are taken into account. Voluntary speed reductions have to be also considered in order to avoid dangerous effects.
The evaluations are carried out for 4 wind speeds (10 m/s, 15 m/s, 20 m/s and 25 m/s) and a rage of heading angles between 0° (fore wind) and 180° (aft wind) with a step of 10°. For all combinations, the wind forces in x and y direction as well as the yaw moments are calculated using the method suggested by Isherwood. Based on the results obtained for the two different ships considered in the present study, some important conclusions have been formulated. It has to be underlined that, during the preliminary design stages, such kinds of evaluations are not very often considered and serious problems could arise during navigation. A customized evaluation has to be based on the specific information related to the characteristics of the inland navigation areas. The evaluations of the hydro-aerodynamic loads for a range of ship speeds, heading angles and wind speeds and their effects have been carried out for two types of river ships: a Port Container 156 TEU and a Chemical Tanker of 5300 m^3. In order to be able to evaluate the influences of the above mentioned parameters, the selected ships have similar main dimensions, similar frontal projected areas above waterline but, the lateral profile areas above waterline are significantly different the ratio being about 1/3. The main characteristics of the two ships are presented in Table 1 and Table 2.

Table 1
Main characteristics of the Chemical Tanker (ChT)

Main characteristics	**Full scale**
Length overall, L_{OA}	135.0 m
Length of waterline, L_{WL}	134.005 m
Length between perpendiculars, L_{PP}	132.421 m
Molded breadth, B	13.45 m
Volumetric displacement, ∇	5363.2 m^3
Design draught, T	3.3 m
Longitudinal centre of gravity, x_G	65.647 m
Block coefficient, C_B	0.904
Waterline area coefficient, C_W	0.945
Amidships section coefficient, C_M	0.998
Lateral projected area, A_L	326.4 m^2
Frontal projected area, A_T	66.74 m^2
Propellers number, n_p	2
Propeller diameter, D_p	1.8 m
Blades number, Z	5
Pitch ratio, P/D_p	0.70
Rudders number, n_R	2
Rudder area, A_R	3.6 m^2
Ship speed, v	16 Km/h / 4.45 m/s

[1] Corresponding author: liviu.crudu@nasdis.ro

Table 2
Main characteristics of the Port Container (PC)

Main characteristics	Full scale
Length overall, L_{OA}	135.0 m
Length of waterline, L_{WL}	134.7 m
Length between perpendiculars, L_{PP}	133.2 m
Molded breadth, B	11.33 m
Volumetric displacement, ∇	4253,2 m^3
Design draught, T	3.0 m
Longitudinal centre of gravity, x_G	68.39 m
Block coefficient, C_B	0.929
Waterline area coefficient, C_W	0.987
Amidships section coefficient, C_M	0.993
Lateral projected area, A_L	986.23 m^2
Frontal projected area, A_T	67.23 m^2
Propellers number, n_p	2
Propeller diameter, D_p	1.5 m
Blades number, Z	4
Blade area ratio, BAR	0.70
Pitch ratio, P/D_p	0.90
Ship speed, v	20 Km/h / 5.56 m/s

2. Evaluation of hydrodynamic and aerodynamic forces and moments

As a first step the resistance was calculated for a range of advance speeds without taking into account the influence of the wind speed and direction. Additionally, in order to be able to evaluate the speed losses due to the wind acting in x direction, a number of 4 wind speeds have been considered. By taking into account the wind direction relative to the ship, polar diagrams have been draw up, allowing the possibility to evaluate the total resistance in any direction. The wind direction has been taken into account in a range between 0° and 180° with a step of 10°. Consequently, the evaluation of the lateral forces and yaw moments has been also performed based on the calculations of the wind coefficients according to Ysherwood method.

2.1. Calculation of hydrodynamic and aerodynamic longitudinal forces

For both ships the evaluation of the resistance has been performed using Holtrop – Mennen (Holtrop at all, 1982) method for a range of speeds specific for each ship. It has to be mentioned that the results do not take into account the river water flow which is depending on the location and, moreover, can be easily considered in the calculations. The aerodynamic components of the resistances due to ship speeds are included in the evaluations. The comparative results for the two ships, the Port Container (PC) and the Chemical Tanker (ChT) are presented in Fig. 1. Mention should be made that the Chemical tanker is equipped with classical rudder configuration while the Port Container has a steering nozzle system.

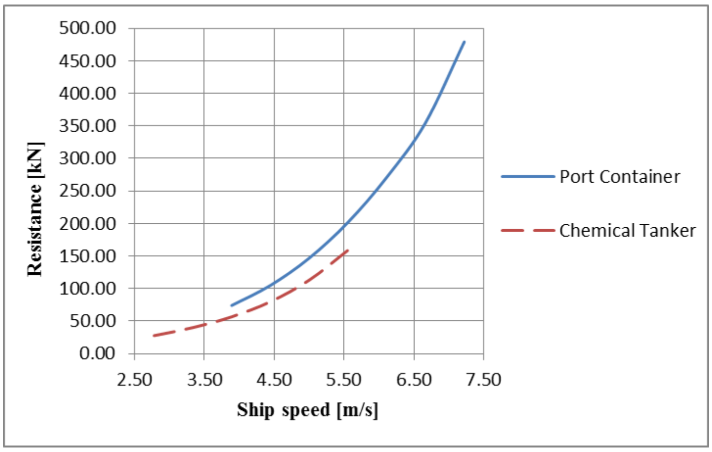


Fig. 1.
Comparative results of resistances for the two ships

The results of the calculations related to the speed loss of the ship due to wind action in x direction (fore wind) are shown in Fig. 2 and Fig. 3.

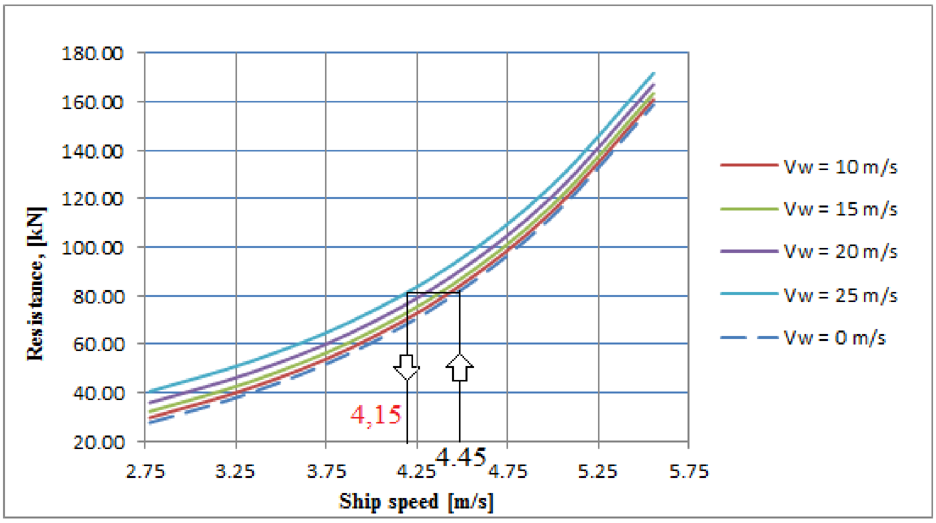


Fig. 2.
Speed losses due to wind action for the Chemical Tanker case

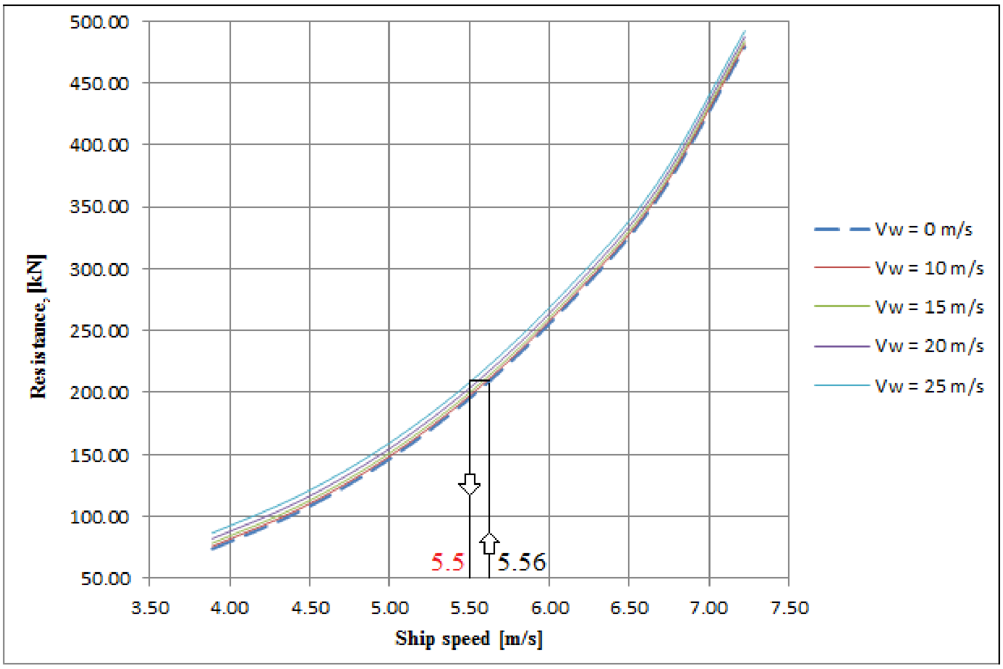


Fig. 3.
Speed losses due to wind action for the Port Container case

It can be seen that the speed losses due to frontal wind action are practically negligible. For the largest wind speed used for calculations, 25 m/s, the speed loss is only about 0.3 m/s (1.1 km/h) for the Chemical Tanker and 0.06 m/s (0.22 km/h) for the Port Container, respectively. Similar diagrams have been made for the effective power as a function of ship speed and wind speed being possible to evaluate the necessary additional power required to keep a constant speed for a given ship speed and a certain wind speed in the investigated range. As previously mentioned, the calculations of the wind forces have been made based on the evaluation of aerodynamic coefficients according to the method suggested by Isherwood (Isherwood, 1982). The aerodynamic coefficients in longitudinal direction C_X as function of wind direction are calculated using formulas resulting from regression analysis of a large amount of experimental tests. As a matter of fact, the best solution would be the direct evaluation of the aerodynamic coefficients based on wind tunnel tests (Crudu, 2015) when the real exposed areas can be modeled and tested. In this case experimental facilities are required. The big advantage is that some other useful tests can be carried out, cheaper than the hydrodynamic ones, like preliminary analysis and optimization of hull forms.

The influence of wind direction on the total resistance of ship can be represented using polar diagrams which are giving a global overview. The results obtained for both ships are presented below in Fig. 4 for the Chemical Tanker and Fig. 5 for the Port Container.

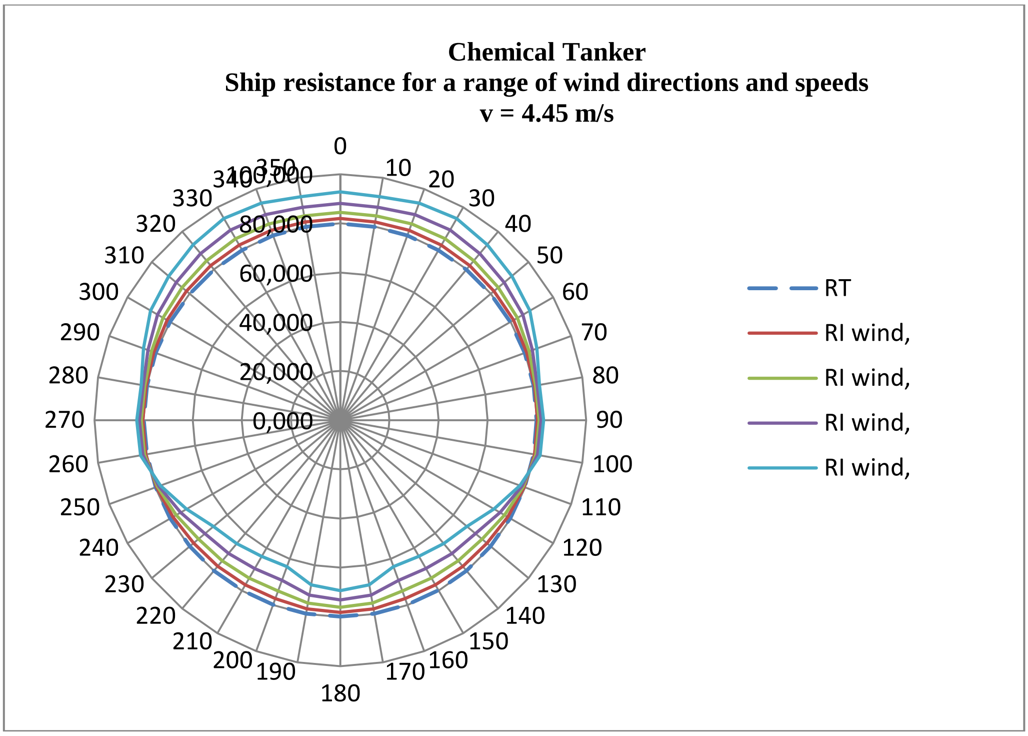


Fig. 4.
Polar diagram of ship resistance for the Chemical Tanker

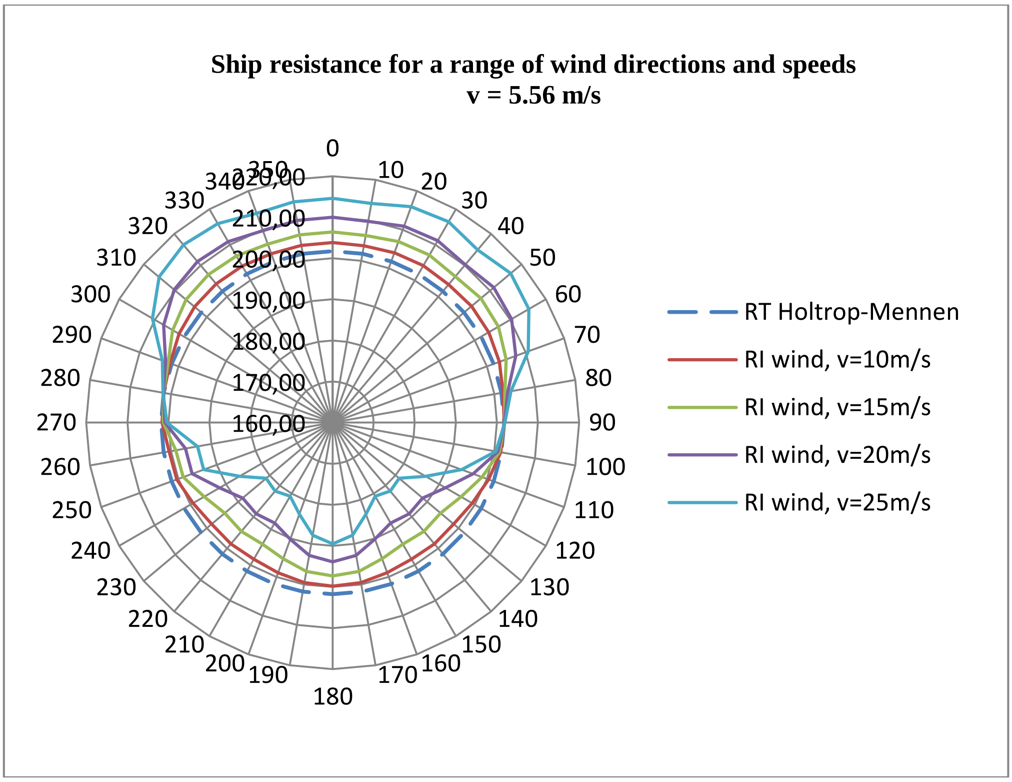


Fig. 5.
Polar diagram of ship resistance for the Port Container

2.2. Evaluation of aerodynamic lateral forces and yaw moments

The evaluation of lateral forces and yaw moments is performed using the above mentioned procedure. This time the coefficients in transversal direction C_Y and the yaw coefficients, C_N, are calculated using specific given formulas. The graphical representations are in Fig. 6 and Fig. 7 for C_Y coefficients and in Fig. 8 and Fig. 9 for the C_N ones, together with the polynomial approximations. These approximations, in fact mathematical formulations, could be very useful in order to solve the equations of equilibrium under the wind excitation forces and moments.

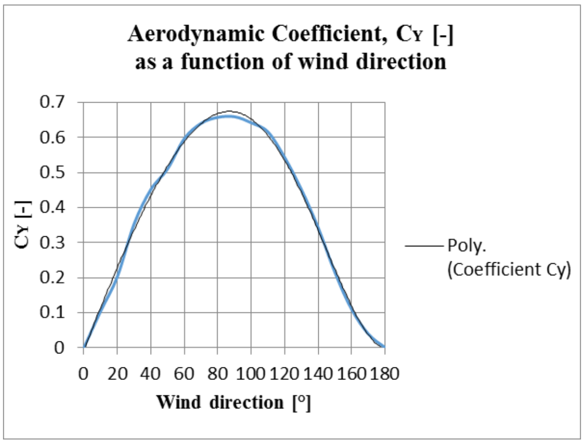


Fig. 6.
Aerodynamic lateral coefficient – Chemical Tanker

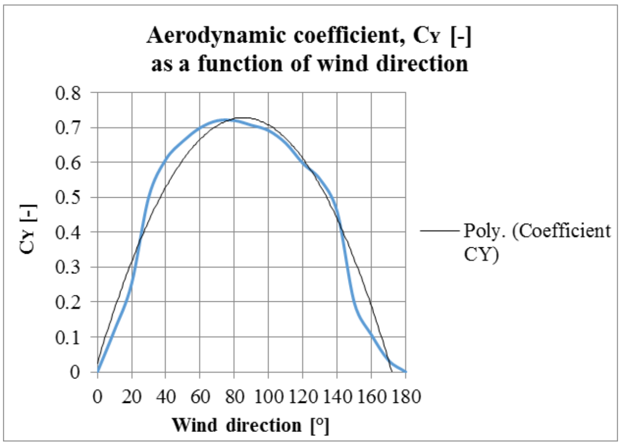


Fig. 7.
Aerodynamic lateral coefficient – Port Container

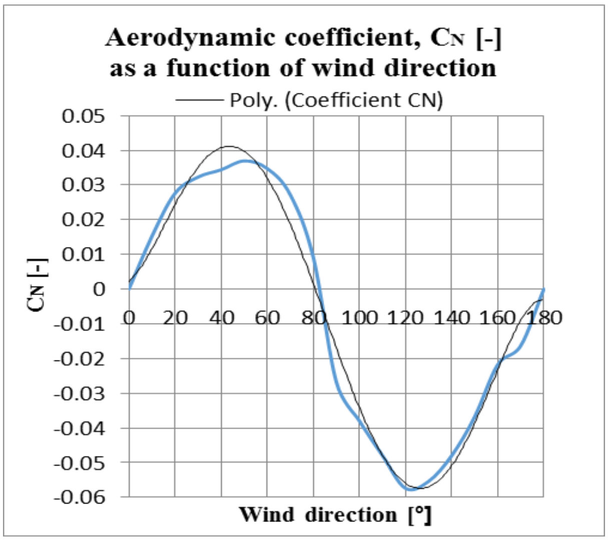


Fig. 8.
Aerodynamic lateral coefficient – Chemical Tanker

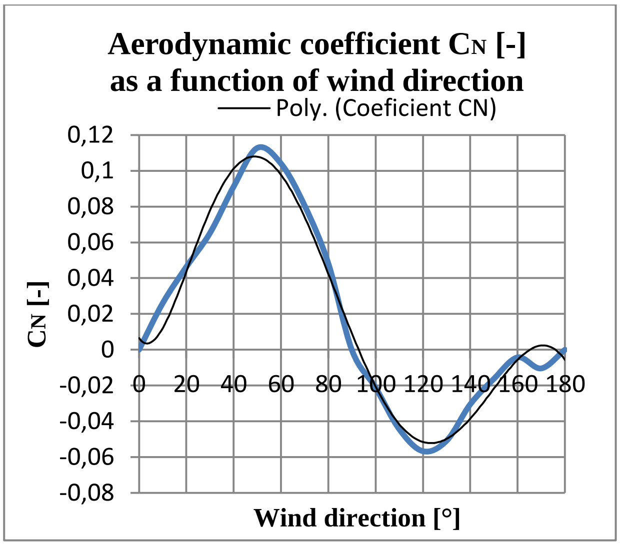


Fig. 9.
Aerodynamic lateral coefficient – Port Container

Using the aerodynamic coefficients it is now possible to calculate the aerodynamic forces and moments which have to be compensated by the bow thruster and the rudder (the case of the Chemical Tanker) or by the bow thruster and the steering nozzle system (the case of the Port Container). Between the main elements which have to be taken into account in order to be able to define the most suitable solution in the preliminary design stages are:
- The aft part configuration of the body and the propulsion configuration both influencing the rudder geometry and its hydrodynamic characteristics;
- The opportunity to use a steering nozzle propulsion system which is also depending on the aft geometry influenced by the engine room arrangement;
- The geometry and performances of the bow thruster which are influenced by the fore geometry and the draft which has to be adapted in order to navigate in restricted waters. This will strongly influence the diameter of the bow thruster.

According to the above mentioned observations, the following active elements have been evaluated in order to identify the forces and moments necessary to counteract and to keep the ship in safe condition:

- For both ships, based on the information provided by the body plan and the general arrangement, the performances of the bow thrusters have been calculated for a range of diameters using computer codes developed in the research department of the Faculty of Naval Architecture (Obreja at all, 2015) . Then, the lateral forces, Y_0 and the yaw moments, N_0, related to the pivoting point defined as aft amidships with 1/6 L_{PP}, became available.
- For the Chemical Tanker hydrodynamic calculations have been performed, using the above mentioned package of applications, for a rudder having a NACA 0015 profile and then the lateral forces Y_R, and moments N_R, were available.
- Based on powering calculations, using the in house computer code already mentioned, it became possible to evaluate the lateral forces Y_P and N_P.

In Fig. 10 are presented the dependency of the lateral forces on wind speed and direction for the Chemical Tanker. The horizontal lines represent the total lateral forces provided by the bow thruster for 3 different diameters added by turn to the maximum force provided by the rudder. It can be observed that the lateral aerodynamic force corresponding to a wind speed of 25 m/s can be compensated if a diameter of 1.2 m can be used.

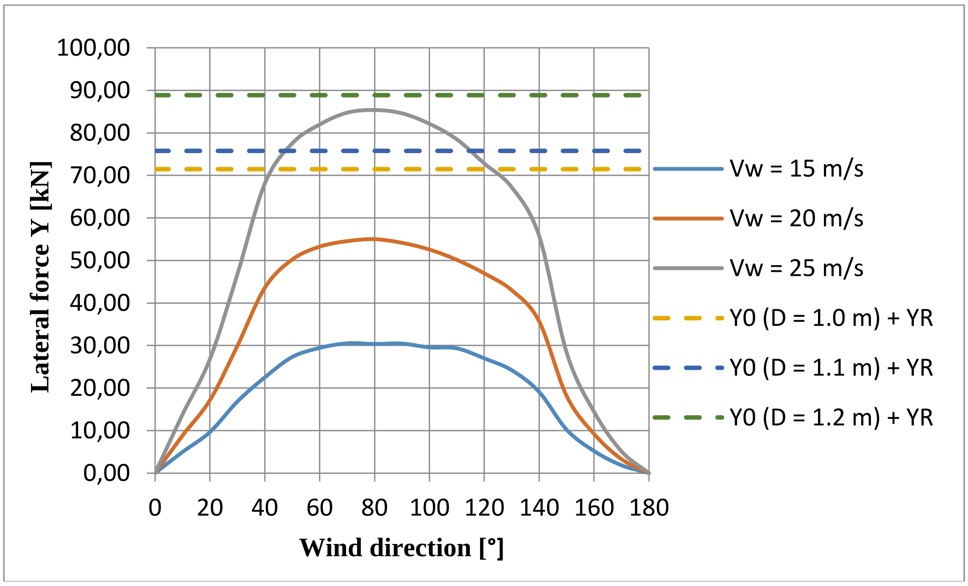


Fig. 10.
Chemical Tanker - Wind lateral forces for 3 speeds and available compensation forces generated by the bow thruster and the rudder

A similar situation has been identified for the Port Container. This case is presented in Fig. 11. Unfortunately, larger diameters of the bow thrusters can't be afforded due to the limitation of the draft if navigation case with empty containers is considered and the draft could reach low values in the range of 1.5 m. Consequently, higher lateral wind speeds than 22 m/s cannot be compensated and have to be stated in appropriate documents for the ship master.

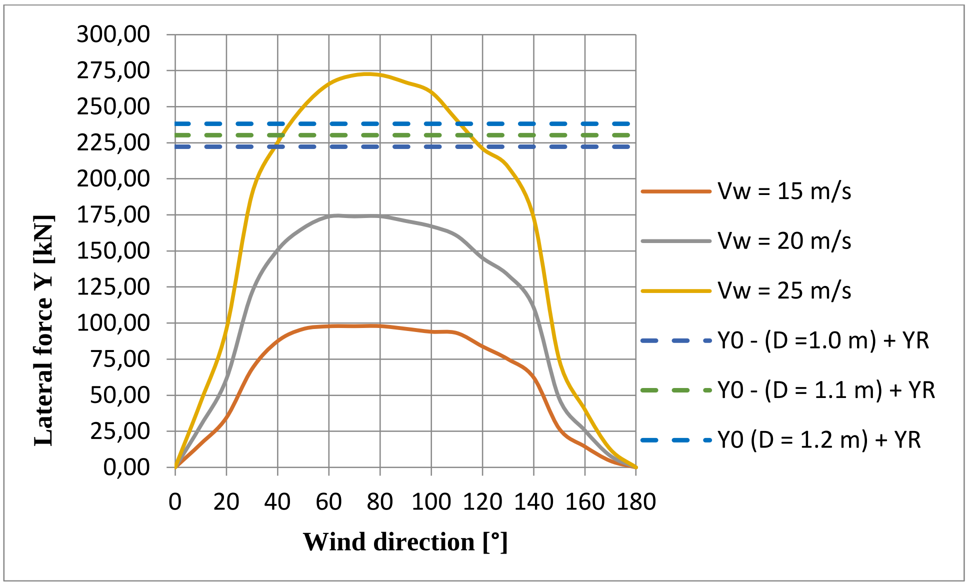


Fig. 11.
Port Container - Wind lateral forces for 3 speeds and available compensation forces generated by the bow thruster and the rudder

It has to be noticed the significantly higher values for the Port Container case due to the about three times higher value of the lateral projected area.
Similar calculations have been performed in order to evaluate the aerodynamic yaw moments due to wind and the total compensating yaw moments provided by the rudder (ChT), bow thrusters and the propulsion system (PC). It has to be underlined that all moments have been calculated using as reference to pivoting point, commonly used in maneuverability calculations and simulations. The results are presented in Fig. 12 for the Chemical Tanker case and in Fig. 13 for the Port Container one. The Fig. 12 is clearly showing that the aerodynamic moments can be compensated using only the moment created by the rudder for a deflection angle of 25°. The moments due to the bow thruster are not

represented and, in fact, are not necessary in order to compensate the wind yaw moments. Mention should be made that the moments generated by the bow thruster are much larger the ones generated by the rudder. However, the reason to have a bow thruster on board is mainly dictated by the necessity to have good maneuverability performances at low speeds of the ship in restricted waters. Consequently, minimum diameter of the bow thruster can be considered.

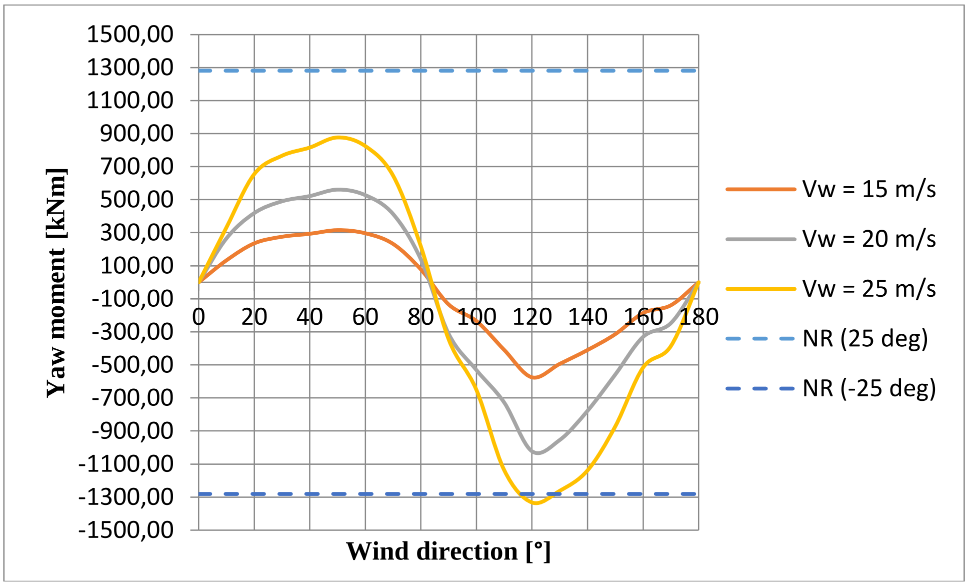


Fig. 12.
Chemical Tanker – wind yaw moments and the rudder moment, N_R

The case of the Port Container is presented in Fig. 13. The minimum moment, necessary to compensate the wind moments, can result from the combination of the moments given by the bow thruster corresponding to its minimum diameter, D = 0.9 m and the moment created by the propulsion system for a deflection angle of 25°. A larger diameter of the bow thruster and a larger deflection angle of the steering nozzles will lead to much larger moments.

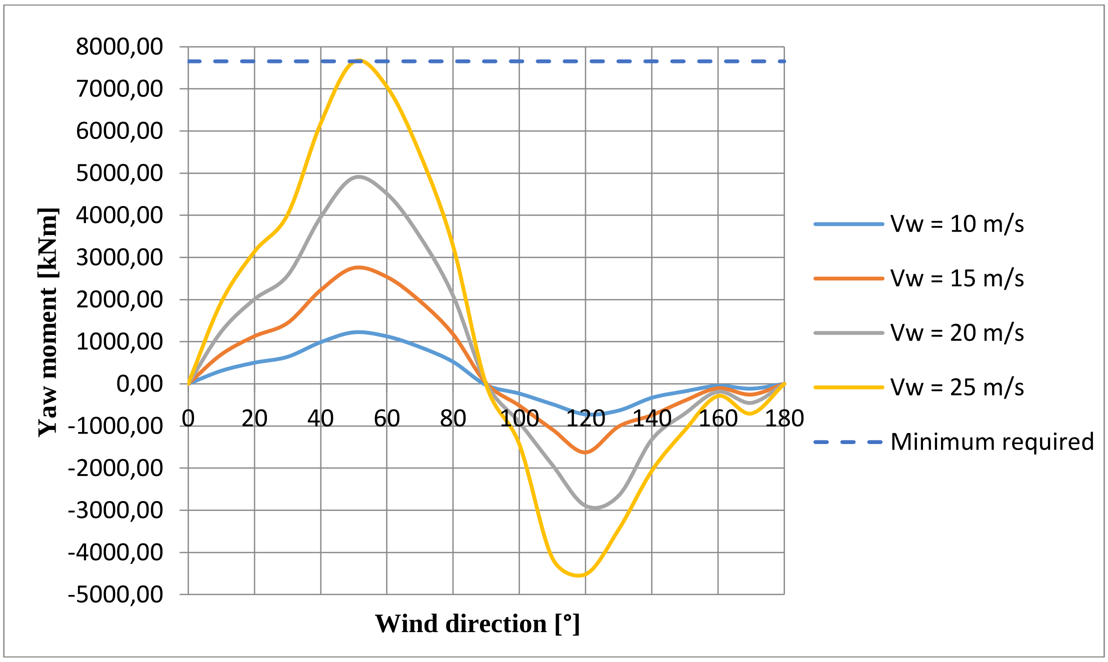


Fig. 13.
Port Container – wind yaw moments and the minimum required moment

In order to better identify the influences of the lateral and frontal projected areas synthetic diagrams are presented below for both ships. The Fig. 14 refers to the lateral wind forces, Y_W, while the Fig. 15 is dealing with the aerodynamic yaw moments, N_W.

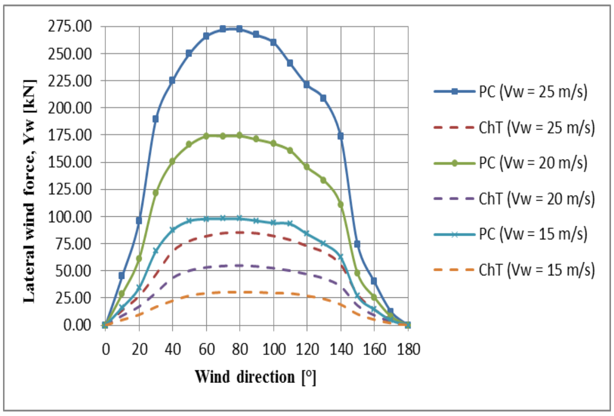


Fig. 14.
Comparative aerodynamic lateral forces, Y_W, as function of wind speed and direction

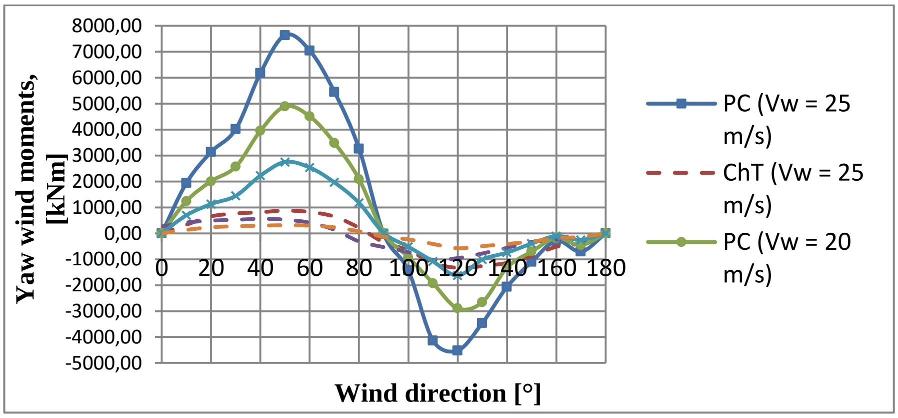


Fig. 15.
Comparative aerodynamic yaw moments, N_W, as function of wind speed and direction

Generally, as already mentioned, the procedure to be used in order to find the most appropriate solutions is based on the equations of equilibrium.
- On one side it has to be defined and calculated wind forces and moments which have to be compensated, Y_W and N_W.
- On the other side it is necessary to perform the evaluation of the forces and the moments provided by the steering system, Y_R and N_R in case of rudder and/or Y_P and N_P in case a steering nozzle propulsion system is considered and also the forces Y_0 and moments N_0 generated by the bow thrusters.

If all these parameters can be mathematically defined, as shown in Fig. 6 to Fig. 9 for the aerodynamic coefficients, then a system of equations can be built having as possible variables, depending on the matter in focus:
- The bow thruster diameter speed of rotation or power absorption, etc.;
- The type of rudder to be used (Bosoanca et all, 2013), the geometric characteristics of the rudder, etc.;
- The characteristics of the propulsion system.

In Fig. 16 and Fig. 17 there are given two examples regarding the possibility to formulate a mathematical description of the dependence of the bow thruster forces, Y_0 and moments, N_0, on the diameter using polynomial functions. The example is for the bow thruster design for the Chemical Tanker. A similar example can be developed for the Port Container case.

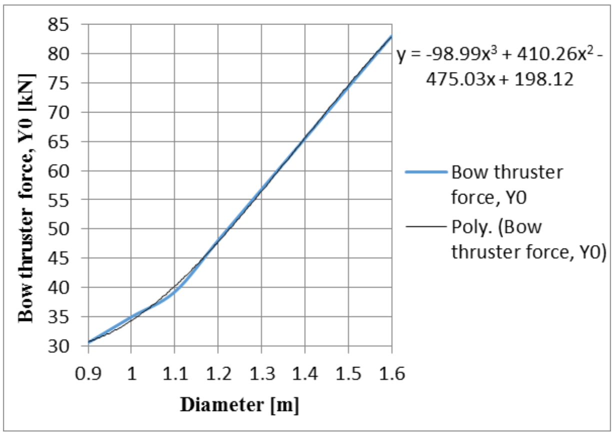


Fig. 16.
Bow thruster forces, Y_0, as function of diameter (Chemical Tanker)

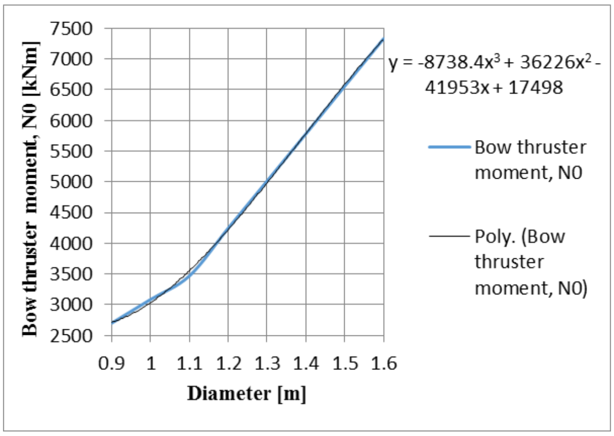


Fig. 17.
Bow thruster moments, N_0, as a function of diameter (Chemical Tanker)

In Fig. 18 and Fig. 19, which are presented having in mind the evaluation of the effectiveness of the two steering systems, are displayed the moments created by the rudder for the Chemical Tanker and the steering nozzle system used for the Port Container. In both cases the results are defined related to the pivoting point. It has to be noticed the much higher moments generated by the steering nozzle as compared to those provided by the classical rudder configuration. That is why, in order to counteract the high aerodynamic forces and moments, the steering nozzle system was chosen. These results have to be correlated to the information provided by Fig. 12 and Fig. 13. The simple linear dependency of the moments generated by steering nozzle system against the nozzle deflection angle could lead to simplified models which can be used at least during the preliminary design stages.

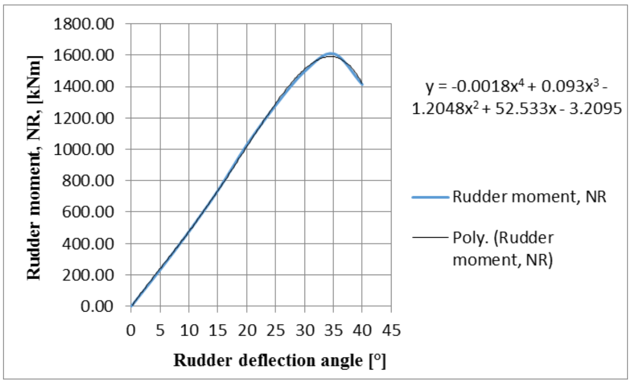


Fig. 18.
Rudder moments, N_R, as function of deflection angle (Chemical Tanker)

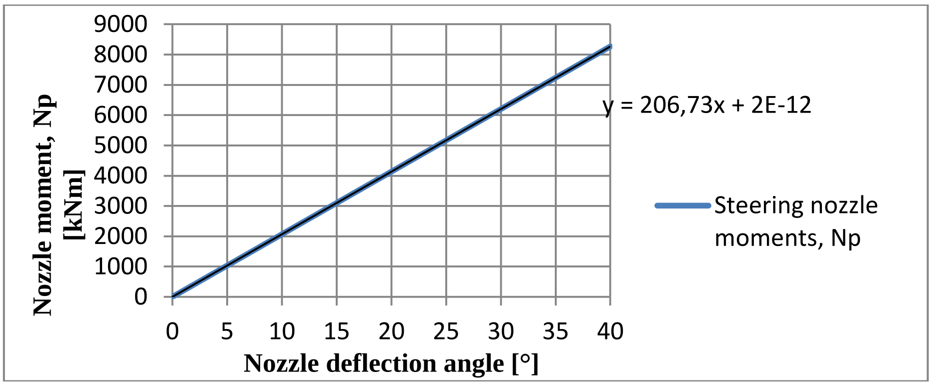


Fig. 19.
Steering nozzle moments, N_P, as a function of deflection angle (Port Container)

3. Conclusions

The evaluation of aerodynamic forces and moments has been performed using the method developed by Ysherwood because of the relatively simple formulas based on statistics which are not dedicated to river ships. Consequently,

different other more suitable methods could be used if such systematic investigations exist. However, the best ways to perform such kind of calculations have to be based on aerodynamic tests, using dedicated facilities like wind tunnels.
It was clearly shown that speed losses due to aerodynamic forces do not play an important role in case of river ships. On the contrary, the aerodynamic lateral forces and moments could play a decisive role depending on the navigation areas. Unfortunately, such kinds of estimations are carried out very seldom, the main concern being only related to the stability criteria, mainly required by the classification societies.
The results presented in this paper are not taking into account the river water flow speed downstream or upstream. It refers only to still water case but, if systematic information related to the navigation areas exists, these can be easily taken into consideration for computations.
All moments are expressed considering the pivoting point, commonly used in maneuverability applications.
The steering nozzle system is much more effective as compared to the rudder arrangement (Crudu, at all, 1988), the generating lateral forces and moments having much higher values. Moreover, the maneuverability qualities are significantly increased from the point of view of zig – zag maneuvers which are very important in case of inland navigation as compared to course keeping stability.
The evaluations of some maneuverability characteristic have been evaluated for both ships. The results, which are not presented in the present paper, are proving that the stability on route, evaluated by the calculation of linear stability coefficient, is according to the standards. Moreover, the turning ability of the ship is determined on the basis of turning circle characteristics and it fulfills the IMO criteria.
During the next design stages, using CFD applications or hydrodynamic tests using Planar Motion Mechanism (PMM), the hydrodynamic derivatives can be evaluated (Obreja at all, 2010), and a more general mathematical model can be developed and customized according to the required application.
The aerodynamic forces and moments are also important when large convoys of barges are pushed in canals mainly in open areas. It is commonly happening to lose the control due to strong winds or wind gusts which could suddenly appear. Such configurations do not have specially design means to be able to counteract the forces and moments generated by the wind. A relatively simple solution is to use a detachable module, having incorporated a bow thruster which can be remotely controlled, placed in front of the convoy. For ecological reasons, electric engines powered also using alternatively a set of electric of batteries can be also used. Another solution which was used in the past consists in connecting the pusher to the convoy using hydraulic cylinder, the pusher being now able to act itself like a rudder for the convoy. In principle, in both cases, the same procedures like those exposed in the present paper can be successfully used.

Acknowledgements

The authors would like to express their gratitude and thanks to NASDIS Consulting SRL, Galati, Romania, for the continuous support offered in developing relevant research activities and providing valuable information which plays an important role in developing reliable practical applications.

References

Bosoanca, R.; Crudu, L.; 2013. Influence of aft modifications on maneuverability characteristics of a tanker based on full scale trials, *Annals of „Dunarea de Jos" University of Galati, Fascicle XI–Shipbuilding, Year XXX*, 109-119, Galati University Press, Galati, ISSN 1221-4620.
Crudu, L.; Drăgan, D.; Voinescu, R. 1988. Experimental Research on the Influence of the Steering Gears Systems on Some Maneuverability Characteristics of the River Push boats, *17-th SMSSH*, Vol. II: 45.1-45.5, Varna, Bulgaria.
Crudu, L. 2015. *Theoretical and experimental applications in offshore engineering (in Romanian)*, University Foundation Press, „Dunarea de Jos" ISBN 978-973-627-548-7, 210 p.
Holtrop, J.; Mennen, G.GJ. 1982. An approximate power prediction method, *International Shipbuilding Progress,* 29(335): 166-170.
Isherwood, R.M. 1973. Wind Resistance of Merchant Ships, *Transactions of RINA*.
Obreja, D.C.; Nabergoj, R.; Crudu, L.; Păcuraru, S. 2010, Identification of Hydrodynamic Coefficients for Maneuvering Simulation Model of a Fishing Vessel, *Ocean Engineering*, 37(8-9): 678-687, ISSN 0029-8018.
Obreja, C.D.; Crudu, L.; Păcuraru, S. 2015. *Ship Maneuverability – Guide for numerical applications (in Romanian)*, University Foundation Press, „Dunarea de Jos" – Galaţi, ISBN 978-973-627, 99 p. (in electronic format).

THE DANUBE RIVER FLOW ANALYSIS IN CRITICAL POINTS OF THE FAIRWAY

Gabriel Popescu[1], Leonard Domnisoru[2], Mihaela Amoraritei[3], Alina Modiga[4]
[1,2,3,4] *"Dunarea de Jos" University of Galati, Faculty of Naval Architecture, Galati, Romania*

Abstract: An ongoing concern for all companies that manage fairways of rivers is to ensure conditions for navigation all year round even in the periods of low water levels. The long experience and the results of statistical analyses developed by the A.F.D.J. (Lower Danube River Administration) company have revealed a set of critical points on the fairway of the Danube River in Romanian sector. Critical points are those parts or zones of the fairway, in the periods of dry weather, when water levels are very low, so that the Danube drafts restrictions occur for ships navigation. This paper includes the analyses of the river flow at critical points in order to identify the medium and long-term solutions that will ensure smooth river traffic, based on a partnership between the "Dunarea de Jos" University of Galati and the A.F.D.J. The study method used is the numerical analysis C.F.D. (Computational Fluid Domain). The 3D modeling of the fairway at critical points was achieved by C.A.D. software, based on the bathymetric measurements. The 3D models were imported in a general C.F.D. software application for the analysis of the critical Danube flow points. The C.F.D. analysis results are presented as the flow lines of the analyzed fluid. Based on the results obtained by C.F.D. analysis, there can be identified the main causes that defines a point on the fairway of the Danube to be considered as a critical one.

Keywords: Danube, fairway, 3D modeling, computational fluid domain, fluid flow critical points.

1. Introduction

In Romania the maintenance activities, by providing optimal conditions for navigation on the Danube fairway, are made by the Lower Danube River Administration A.F.D.J. This company continuously monitors the depth of the fairway by bathymetric measurements. Where depths are less than the values of safety (7.30 m) the dredging works are carried out.
The management of the fairway on the Romanian Danube river sector has led to the identification of zones where the frequency of dredging works is higher. Deposition of the sediments recorded after a dredging process is much higher in those zones. Zones with this feature are called critical points of the fairway.
The study of those zones and the identification of the main causes that lead to the formation of critical points is a necessity. The results of this study can identify the correct zone selected for the dredging operations.

2. Problem formulation

One of the critical point is at the downstream Galati, near the 73 nautical mile, known as the Prut zone (Figure 1). In order to identify the causes that make the Prut zone a critical point (Figure 1), the Danube flow will be analyzed by C.F.D. approach. This numerical study will return the flow lines, velocity and pressures distributions. The analyses of these parameters will enable the formulation of the possible causes of sediments deposition at the Prut critical point.
The flow lines obtained by C.F.D. can be interpreted as directly related to the geometry of the fairway. The speed distributions by CFD study will contribute to the analysis of sediment deposits process. The pressure distributions in the fairway can lead to the formulation of possible causes that make the Prut zone a critical point.

Fig. 1.
Critical Point Prut on Danube River
Source: http://www.harta-romaniei.org

[1] Corresponding author: gabriel.popescu@ugal.ro

3. Computer method

In this study, the C.F.D. analyses of the flow in the critical Danube river zone are done by the XFlow module of the SolidWorks program. This module allows: geometry modeling in fluid domain, fluid characteristics selection, C.F.D. analysis, inlet and outlet boundary conditions, post-processing of the numerical results.
The computer method has the following steps:
Step 1 . Based on data from satellite and bathymetric measurements, the 3D geometry of the zone examined is created. The 3D numerical model is developed by SolidWorks software, with solid elements, using the 3D Face extrude function (Figure 2). The bottom details were generated by the free-form options implemented in the modeling program (Figure 3 & Figure 4).

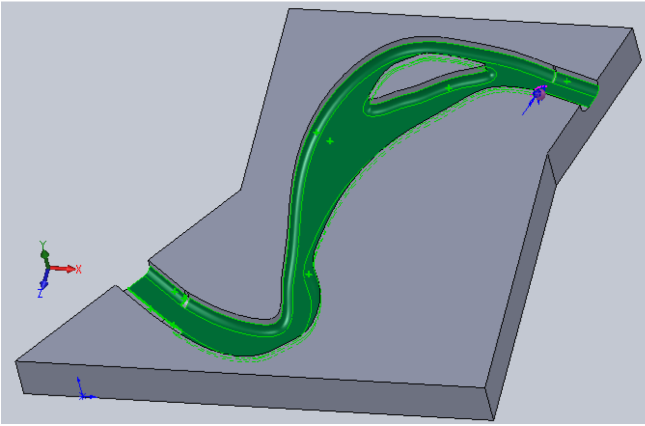


Fig. 2.
3D model for the Prut zone

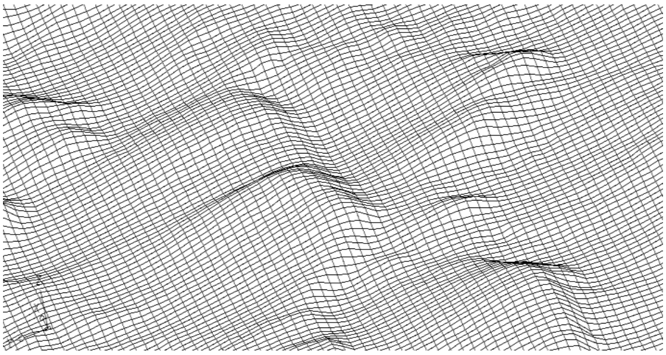


Fig. 3.
3D face for the bottom details
Source: (A.F.D.J. 3D Face export .dxf)

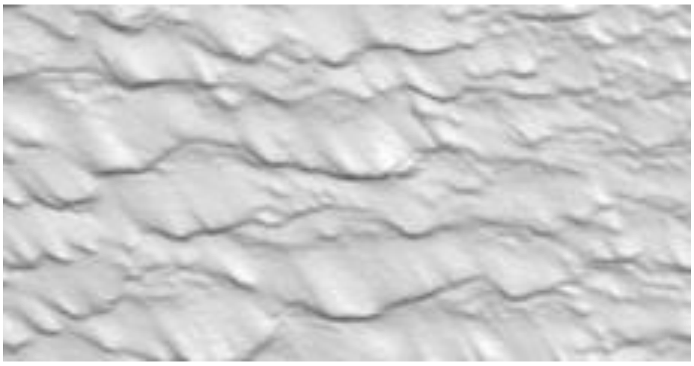


Fig. 4.
3D model for the bottom details
Source: (A.F.D.J. rendered 3D Face)

Step 2. The 3D modeling of the inlet and outlet is made at the input and output sections of the model generated in step1. See figure 5, where I is the inlet surface and O is the outlet surface.

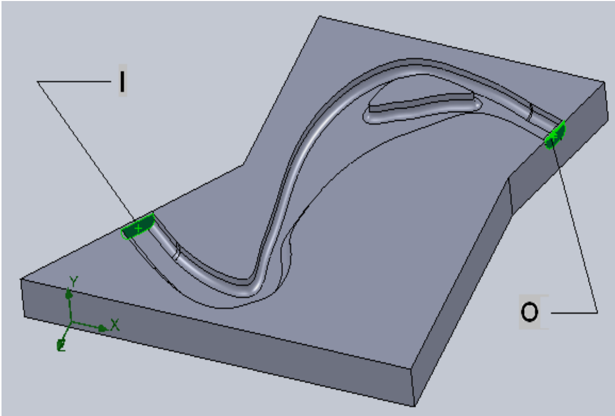


Fig. 5.
3D models for the input and output sections

Step 3. The 3D components generated in steps 1 and 2 are assembled in one numerical model.
Step 4. The parameters for the CFD numerical analysis are defined. At the inlet condition the flow speed is defined. The flow speed is variable over the water domain, being influenced by size, slope roughness of the riverbed. In the water domain the flow velocity increases from the sides towards the middle and from the bottom to the surface of the water channel. The vertical flow velocity is function to the water depth and the presence of obstacles in the riverbed. The outlet condition was defined using the known flow at the exit of the water domain.
Step 5. The numerical model is checked and the C.F.D. analysis is carried on.

4. Numerical results

The CFD numerical analysis results are:

- Distribution of the pressure. Figure 6 shows zones with maximum pressure. The pressure on the banks of the riverbed, in the A zone, is influenced by the particles dislocation and inclusion into the flow,

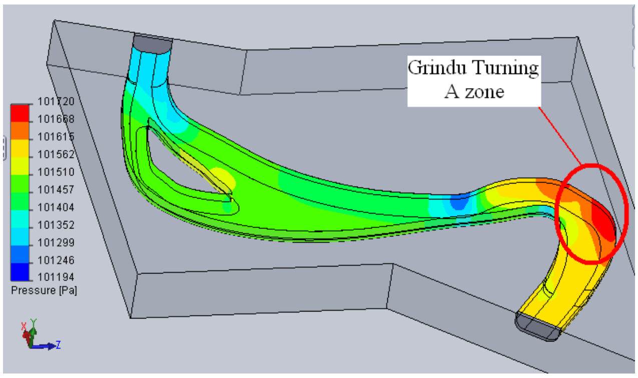


Fig. 6.
The distribution of pressure

- Distribution of flow lines. Figure 7 shows the influence of the Grindu elbow and the northern island from the analyzed zone,

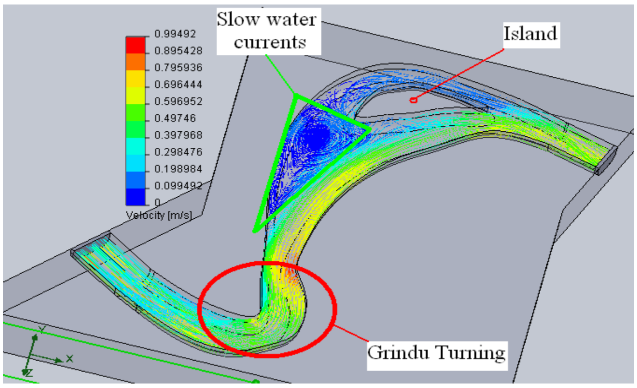


Fig. 7.
The distribution of flow lines

- Charts of speed distributions in different river bed sections (Figure 8).

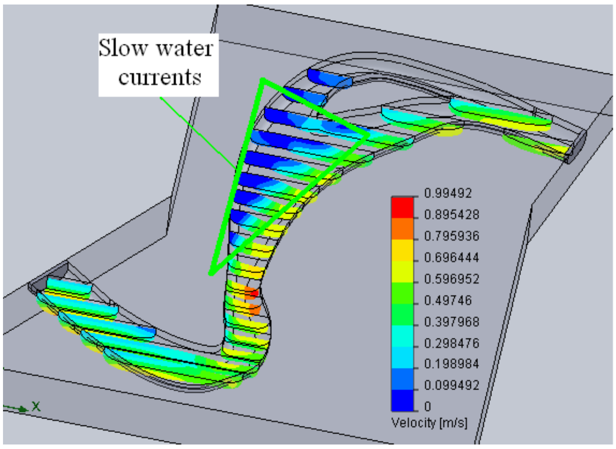


Fig. 8.
Speed charts in different riverbed sections

5. Discussions

Particles dislocation and inclusion into the flow at the river elbow from Grindu turning zone must be analyzed in connection with the results for the distribution of flow lines in Figure 7 and speeds in Figure 8. The velocities decrease in the slow water current zone, influenced by sedimentation, deposition of solid particles taken from the Grindu turning zone. In order to validate the numerical model, the analysis results (Figure 7 & Figure 8) are compared with the bathymetric measurements done in January 2016 (Figure 9) and the flow lines distribution at the end of March 2016 (Figure 10).

Fig. 9.
The bathymetric measurements done in January 2016
Source: (AFDJ Galati)

Fig. 10.
The bathymetric measurements at the end of March 2016
Source: (AFDJ Galati)

It results that the slow water current in Figure 7 and Figure 8 corresponds with declared critical zone (red rectangles) from Figure 9 and Figure 10. It means that the zone where flow rates decreased significantly (green triangle) overlaps with decreasing depth fairway zone by depositing silt particles.
Observation:
The maps of the bathymetric measurements in Figure 9 and Figure 10 contain only the depths for the width of the fairway, taken from the total Danube riverbed.
The map of depths, measured between the ends of March 2016 compared to the January 2016, reveals a significant difference. The particle deposits rates are higher in March over a wider zone of the fairway compared to January.
This study is included in to a macro analysis of the Danube riverbed geometry, focused on the Prut critical zone, and represents the first stage of an ongoing complex analysis.

6. Conclusions

After the analysis of the critical zone Prut from the Danube River, there results that the main cause for the phenomena of sediment deposition and fairway depth decrease is the macro geometry of the Danube elbow. The Grindu zone, placed at the right side of the Danube elbow is subjected to high pressures that lead to dislocation and particle transport. The solid particles are deposited where the river speed is significantly reduced.
The numerical results of this study, based on the macro geometry of the Prut critical zone, makes possible to identify a first solution in reducing the rate of particles dislocation by an efficient alluvial defense through clothing the left bank zone A (Figure 6).

Acknowledgements
The authors wish to thank the A.F.D.J. Galati Company, represented by General Manager Mr. Dorian Dumitru, for the collaboration with "Dunarea de Jos" University of Galati. The partnership agreement signed between those institutions leads to identifying and addressing current issues to ensure river traffic conditions on the lower Danube river zone.

References

AFDJ. 2016. *Bathymetric and velocity measurements on the Danube river*, Lower Danube River Administration, Galati, Romania.
Baranya, S.; Jozsa, J. 2006. Flow analysis in river Danube by field measurement and 3D CFD Turbulence modeling, *Periodica Polytechnica Civil Engineering*, 50(1): 57-68.
Baranya, S.; 2003. Flow Analysis at River Training Works by Means of 3D Turbulence Model: Application in River Danube between Győr and Gönyü (in Hungarian), *MSc Dissertation*, BME Department of Hydraulic and Water Resources Engineering, Budapest, Hungary.
Branya, S.; Jozsa, J. 2004. Investigation of Flow around a Groin with a 3D Numerical Model. In *Proceedings II. PhD Civil Expo.*
Mitoiu, C.; Marin, G. 1999. *Rivers Engineering*, BREN Publishing House, Bucharest, Romania.
Pisota, I.; Zaharia, L. 2003. *Land Hydrology*, University of Bucharest, Geography Faculty, Bucharest, Romania.
Romania Map 2015. Available from internet: < http://www.harta-romaniei.org>.
SolidWorks 2007-2008, Users' Guide, Dassault Systèmes SolidWorks Corporation. Available from internet: < http:// www.solidworks.com >.

NUMERICAL SIMULATION OF A CARGO PLANING BOAT WITH INVERTED KEEL

Adrian Caramatescu[1], **Florin Pacuraru**[2], **Catalin Cristea**[3]
[1,2,3] *"Dunarea de Jos" University of Galati, Naval Architecture Faculty, Galati, Romania*

Abstract: The present study concerns the numerical simulation of the free surface flow around the hull of a composites power boat used for cargo shipping on the Danube River. The flow around planing hulls is complex since it involves different physical phenomena such as thin spray flow, wave breaking, air trapping and turbulent boundary layer. The RANSE VOF solver computation method is employed to evaluate the flow field in planing condition and to estimate the powering requirement. The numerical simulation results are compared to the Savitsky semi empirical method.

Keywords: numerical simulation, composites hull, RANSE VOF, fast inland cargo.

1. Introduction

The cargo boat appeared as a necessity to transport supplies to the remote and isolated Danube Delta villages. The Danube Delta Biosphere Reservation regulations forbid the construction of paved road in the pristine environment therefore the only available mean of transportation remains on the waterways. Additionally, the waterways offer a complete network of channels and river branches deserving all the villages and settlements in the Danube Delta. Each year, a few hundred thousand tourists visit this natural reserve, and this raises the necessity to supply the all the touristic resorts with food and beverages, within the shortest amount of time possible, due to the perishability of the supplies, therefore the boat should be on planning regime and equipped with refrigeration devices. There have been considered the following project prerequisites: composites construction for lightweight hull and maximum loading capacity, with a reasonable powering installed; sterndrive propulsion system with diesel inboard, because of the shallow draught advantage, steering, cooling and exhaust system integration into the assembly, tilting system that allows propeller cleaning if it gets clogged with vegetation and reduction of effective draught; 3.5 tons of cargo capacity, loaded on the deck and into 2 refrigeration units; open deck with lightweight textile covering for minimization of the total weight of the boat; trailerable size for road-worthy transport without special permits.

The resulting design of the cargo boat was an all-composite construction developed using available register scantling rules. The hull has a particular shape, with a wide inverted keel extended in the centerline from aft to fore, resulting in a semitunnel or false catamaran shaped hull. The advantages pursued by this particular shape are a reduction of the draught and the reduction of the resistance by trapping a layer of air inside the semitunnel, thus reducing the friction of the hull in that area. There have also been considered one pair of spray rails and the chine was reversed in order to direct flow along the hull and create additional lift by retaining pressure on the bottom. The main dimensions and form coefficients of the hull are given in Table 1. Figure 2 shows the body plan of the hull. The general arrangement consists in a small open aft cabin for the crew of 2, open deck used as cargo area, refrigeration units area and engine room.

Table 1
Main dimensions and form coefficients of the hull

Dimension	Value
Length overall	9.35 m
Hull length	8.50 m
Waterline length	6.76 m
Block coefficient	0.80
Deadrise angle	12º
Waterplane area	15.71 m
LCF	3.11 m
Wetted surface	18.60 m
LCG	3.00 m
VCG	0.29 m
Beam	2.80 m
Depth	1.10 m
Maximal Draught	0.36 m
Unloaded displacement	2.50 t
Loaded displacement	5.80 t
Payload	3.50 t
Fuel	0.20 t
Crew	2 persons
Navigation range	Danube, zones 3 & 4

[1] Corresponding author: adrian.caramatescu@ugal.ro

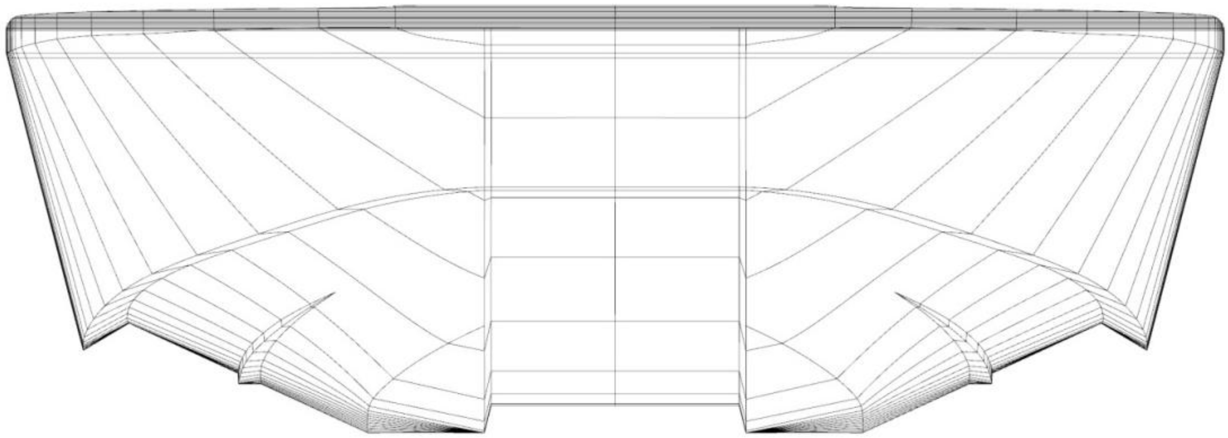


Fig. 1.
Inverted keel planning boat design front view

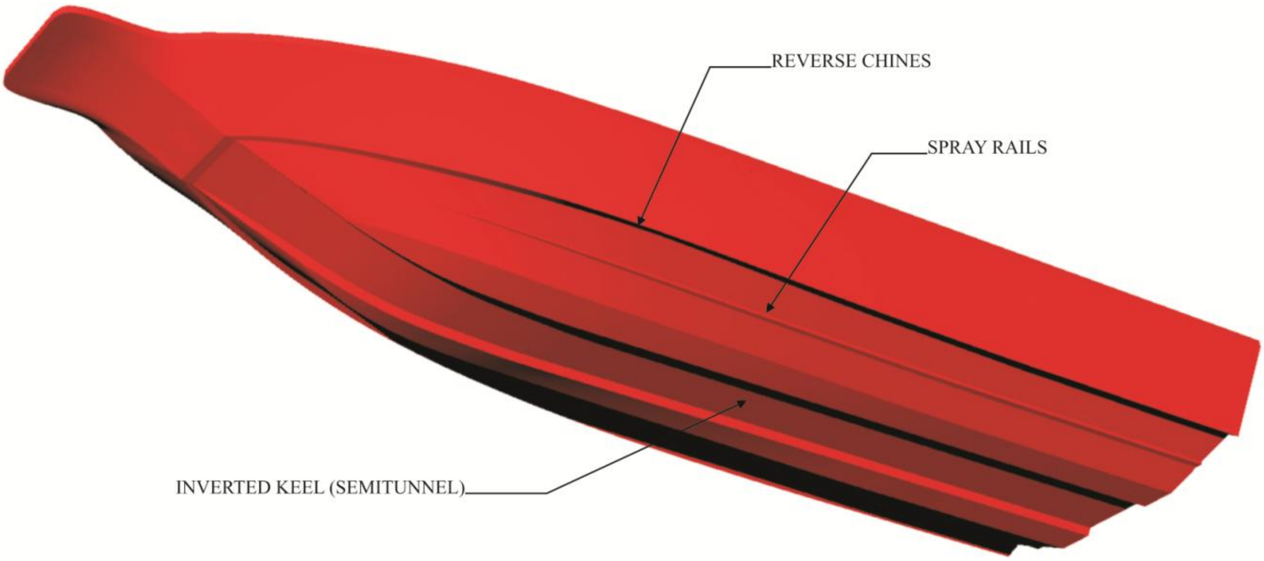


Fig. 2.
Rendered view of the hull design

The availability of the robust commercial Computational Fluid Dynamics (CFD hereafter) software and high speed computing has led to increasing use of CFD for solution of fluid engineering problems across industry and boat building is no exception. CFD based design tools can provide a solution to boat design problems but it requires powerful flow solvers which are able to take into account realistic geometries as well as complex physical phenomena, such as free surface, spray and planing. Accuracy requires careful attention to the physical modeling, particularly to the effects of turbulence, and to the numerical discretization. The difficulty that characterizes the resistance prediction of planing hull is that both viscous and pressure components are related in a non-linear way to the dynamic lift force and trim moment developed by the complex flow on the hull at high speeds. Moreover, the complex multiphase flow associated with high Froude number flows and the development of the spray sheet increase the complexity of the numerical simulation.

During the last decades, several numerical studies on planing hulls have been performed based on the potential flow theory Ghassemi and Ghiasi (2008), Battistin and Iafrati (2003), but their drawback is that they are only valid in the very high speed range and they are not able to capture the steep waves and spray sheets. However, as the computer power steadily increases and better models have been developed to eliminate the drawbacks of potential approach, the hydrodynamic performance and planning behavior are numerically predicted by solving the RANS equations and six degrees of freedom equation, the free surface is simulated by VOF method, Yumin et al (2012), Azcueta (2003), Caponnetto (2001).

This work has focused not only on predicting the hydrodynamic forces and moments, but also the complex multiphase free surface flow field generated by planing boat with inverted keel monohull at high Froude numbers. Volume of fluid (VOF) approach allows the capturing of breaking waves around a ship, including both plunging and spilling breaking waves, the formation of spray, and the entrapment of air.

2. Computational Strategy

A general numerical method to predict planing behavior of a boat is presented in the paper. The NUMECA/FineMarine commercial code is used to compute the flow solution on a multiblock, high-performance parallel computing fashion. The RANS solver is fully implicit, based on finite volume method to build the spatial discretization of the transport equations. The velocity field is obtained from the momentum conservation equations and the pressure field is extracted from the mass conservation constraint, or continuity equation, transformed into a pressure-equation. In the case of turbulent flows, additional transport equations for modeled variables are discretized and solved using the same principles Deng et al (2010), Duvigneau et al (2003). The *k*-ω turbulence model is used for turbulence closure in this paper. Free-surface flow is simulated with a multi-phase flow approach. Incompressible and nonmiscible flow phases are modeled through the use of conservation equations for each volume fraction of phase/fluid Queutey and Visonneau (2007). Velocity-pressure coupling is handled with a SIMPLE like approach. Ship free motion can be simulated with a 6 DOF module. Some degree of freedom can be fixed as well. An analytical weighting mesh deformation approach is employed when free-body motion is simulated. Considering that equilibrium position at high Froude numbers is significantly different from the hydrostatic position, one can expect large mesh deformation. In some case this deformation may leads to negative cells. For practical reasons, the approach employed in this paper splits the problem in two parts: estimation of the hull position for the specific speed and the flow computation around the hull estimated position. In order to start the computation directly from a specific speed, an estimation of the final hull position is necessary. Estimation of the final position may be found from an assumption of the semi-empirical method, a potential code computation or an initial CFD computation. The information targeted are the dynamic trim and sink. In the present work, the Savitsky (1964) semi-empirical method has been employed. For this computation, particular attention will be paid to the previously mentioned problems such as free surface capturing, numerical stability, computation time.
For complex geometries such as a planning boat hull, the grid generation is a very complicated task to accomplish. A Cartesian mono-block unstructured grid of about 2.5 million cells has been generated to cover the entire computational domain along the bare hull. The grid topology is an H-H type. Taking into consideration that planning hulls usually have a very long and narrow wake field, the domain size has to be extended in order to capture the wake correctly. Since the wake development is particularly interesting for planning hull designers, a proper wake field capturing is the key of the computation. The domain covers one ship length upstream of the bow, half above, one and a half ship length out from the side and bottom of the hull, and four ship length downstream of the stern. A noslip boundary condition was enforced at the hull surface, where the first grid point from the body surface was located at around y+=30 for turbulence modeling considerations. A grid refinement has been performed in the stern wake area, on the spray rails and on the free surface as it can be seen in Figure 3. The refinement is cell-based: existing cells are subdivided into smaller cells to locally create a finer grid. Layers of high aspect ratio cells tangentially to the wall have been inserted in order to correctly resolve boundary layers. The technique is based on successive subdivisions of the cells connected to the walls, Wackers and Visonneau (2009).

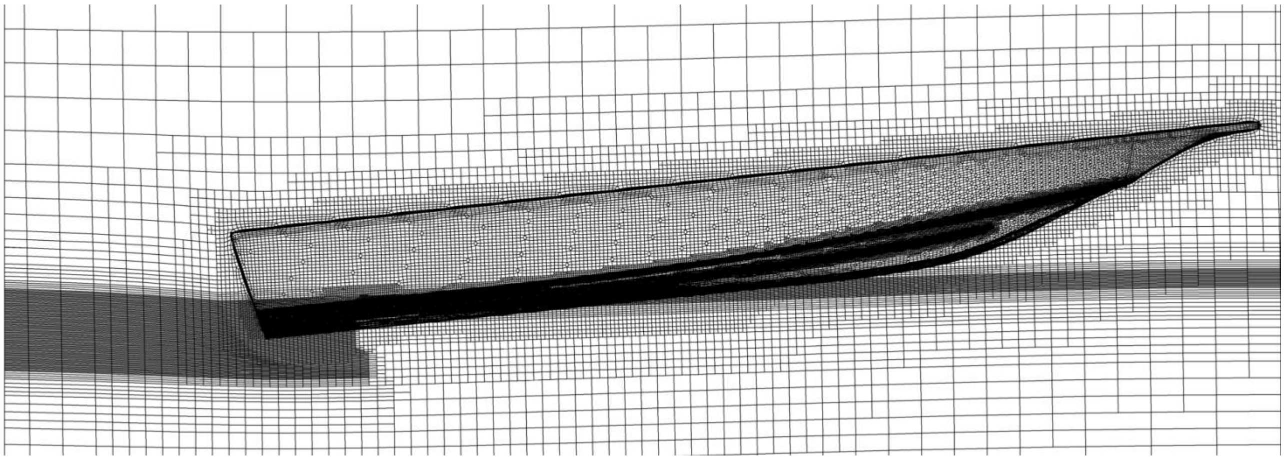


Fig. 3.
Grid refinement

3. Results and Discussion

The present paper introduces a numerical procedure to analyze the free surface flow around a planning boat with inverted keel. The hull form used for analyses have been designed using Rhinoceros and Orca3D plugin commercial software. The hull form has been exported from Rhinoceros to Hexpress in order set up the computational domain, to generate the mesh and to set up the boundary conditions. Finally, the grid has been exported to Fine Marine commercial CFD software which is used for parallel computations
A hull has a planning behavior when the hydrodynamic forces play a dominant role in carrying the boat weight while the buoyancy force is less significant. The hydrodynamic pressure lifts the vessel and also affects the trim angle.

Depending upon Froude number (hereafter Fn), three states of navigation can be identified: displacement state, for Fn<0.4, transition (semi-planning) for 0.4<Fn<1 and planning for Fn>1-1.2. An usual value of the Fn which marks the transition region from non-planning to planning conditions is Fn = 1.0, but other values are used in the literature since the phenomenon has no strict definition, Faltinsen (2006). Increasing the boat speed form zero, the hull passes through different phases from initial hydrostatic condition to the final planning condition. In the first phase, the moving hull begins to create the own horseshoe wave in front of the hull, that travels with the same speed as the body. If the moving body continues to accelerate the stationary horseshoe wave begins to travel with a speed that is slightly smaller than the hull speed, thus leading the hull to begin to climb on the stationary wave also known as hump. The progressive climbing on the hump leads to a modification of the trim angle, also increasing the hull resistance. In the aft part of the boat, the flow for high-speed corresponding to Fn higher than 0.4, separate from the transom stern creating a hollow downstream the transom, that travels with the hull. The experiments shown that an increase of the hollow extension with the Froude number, but on the other hand the hollow width is not particularly affected by the speed, Faltinsen (2006). During this transition phase, particular hull design characteristics as bottom strakes and inverted bilge help increasing the pressure on the bottom panels and separate flow on the sideboards, for reduction of the frictional resistance. This transition phase presents the maximum bare hull resistance. The transition phase ends when the hump moves towards the aft section of the hull. Once the hump passes aft the center of gravity of the boat, the trim angle begins to decrease and the hull resistance decreases too. During this planning state (phase) only a part of the bottom of the hull is wetted and the flow presents multiple turbulences, many induced by the strakes (spray rails) present on the bottom that helps to create a flow separation.

The paper proposes a numerical investigation for solving the viscous free-surface flow based on RANS-VOF method. A series of seven simulations have been carried out for a range of Froude numbers from 0.66 to 1.31, in order to investigate de flow around a boat in semi-planning and planning conditions and also to estimate the power requirements to reach the planning. As long as, in the semi-planning and planning conditions the hydrodynamic pressure lifts the boat and also affects the trim angle, the simulations have been perform considering solved free sinkage and trim for different imposed speeds. One of the most challenging task is to capture the development of very complex flow phenomena as overturning and spray. Simulation performed revealed that in bow area an overturning phenomenon occurs in incipient phase of semi-planning at Fn=0.66, as shown in Figure 4. Spray rails have been used on the hull bottom to increase the lift force by bending the water spray downwards. In order to separate the flow along the sides reversed chine has been considered. The effect of spray rails and reversed hard chine on flow detachment at Fn=0.99 is depicted in Figure 5. Furthermore, in the stern region, water separates from the hull at the transom edge for semi-planning and planning conditions, as one can see in the Figures 6, 7 and 8 and as it was expected, a hollow downstream the transom develops. The hollow modifies its shape and volume dynamically in direct correlation with the speed of the hull, being reduced in depth and increased in length as the speed increases.

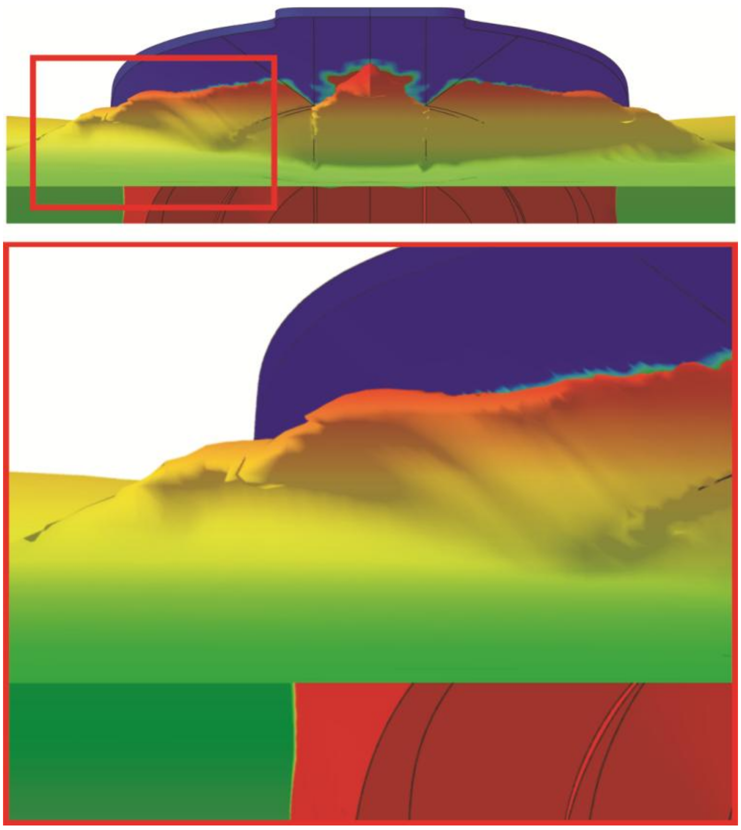


Fig. 4.
Overturning Fn=0.657 (6m/s)

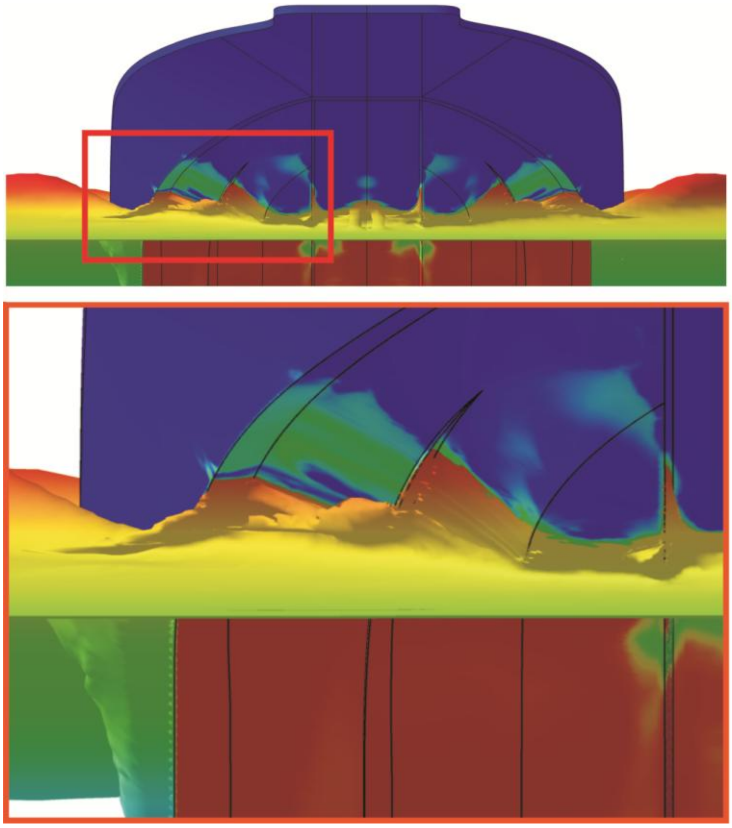


Fig. 5.
Spray sheet Fn=0.986 (9m/s)

The effect of the semitunnel shape design that intended to reduce the total resistance by reducing the frictional resistance with the help of air entrapment was partially achieved, as the mass fraction pictures revealed. Further studies will be conducted with various hull shapes to investigate the air entrapment and total resistance correlation. In Figure 6 there are presented the front, bottom and side view of the wetted hull surface for all the 7 speed cases considered in this study. It can be observed that the planning condition begins in the vicinity of Fn=1. The reversed chines and spray rails play a significant role in directing the flow alongside the hull and creating the intended flow separation.

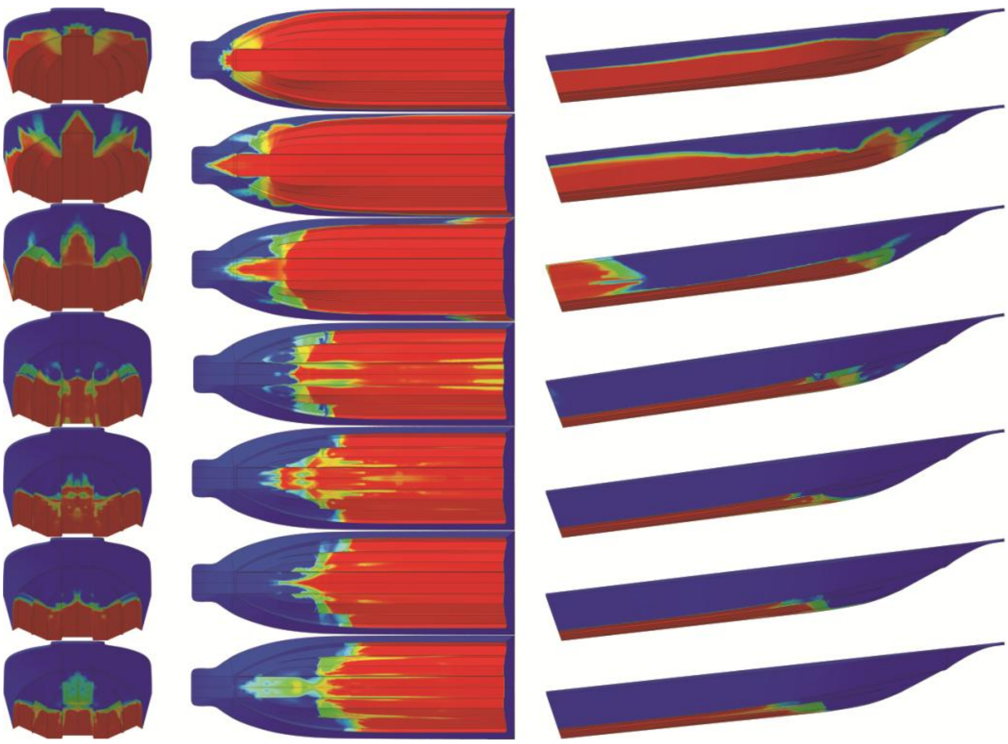


Fig. 6.
Mass fraction distribution along the hull Fn=0.66 (top) to Fn =1.31 (bottom) Blue is air, red is water

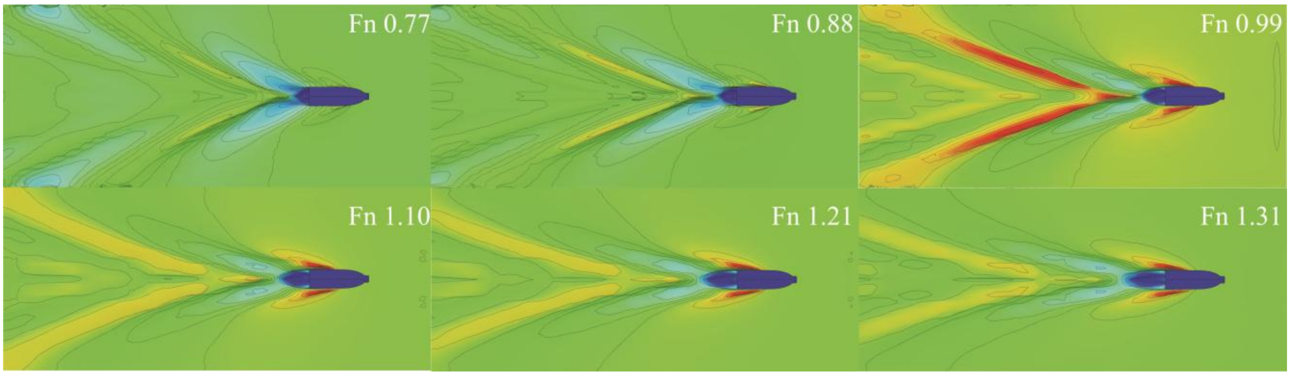


Fig. 7.
Wave pattern at various Froude values

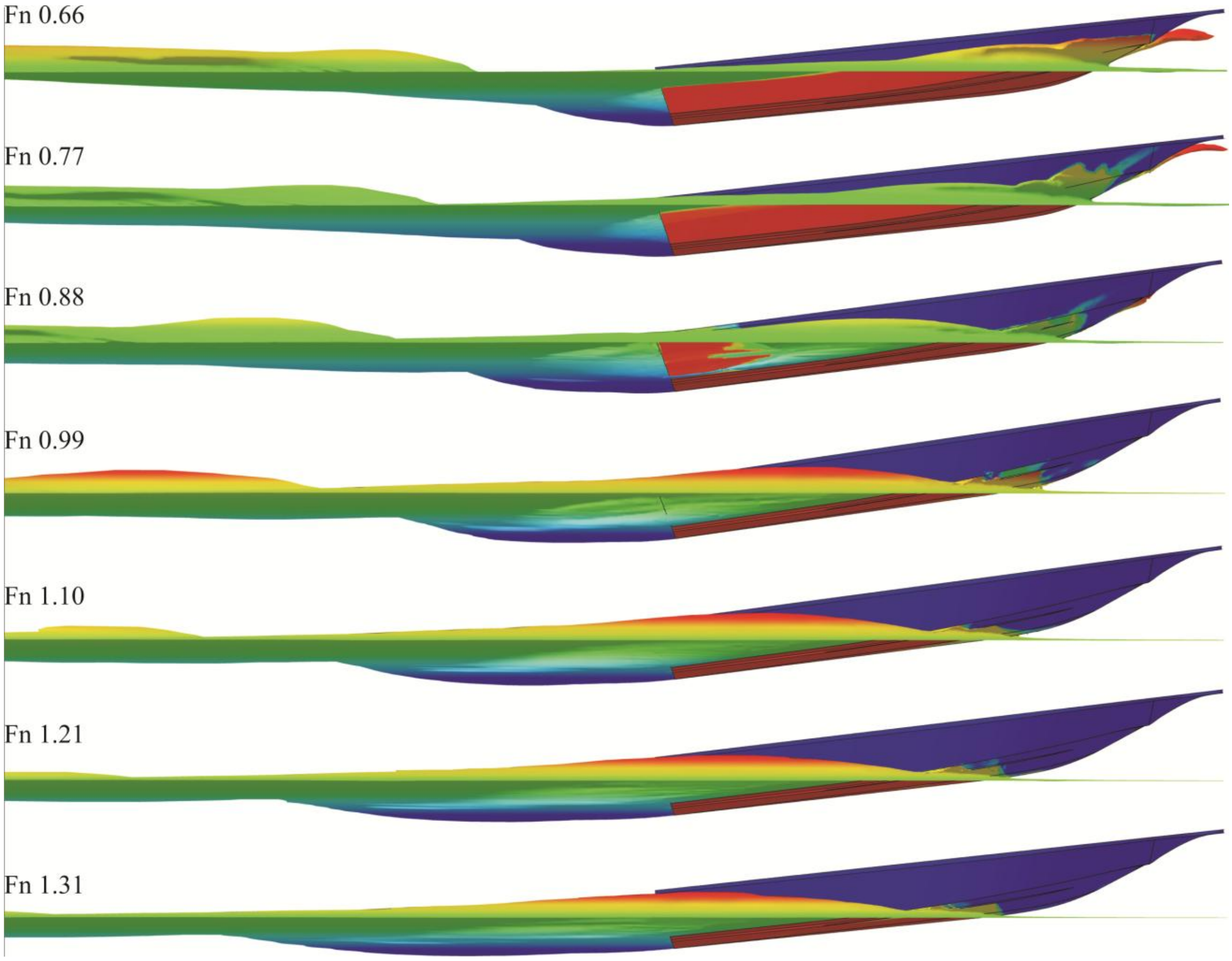


Fig. 8.
Free surface development for Froude numbers comprised between 0.66 and 1.31

3. Conclusion

The method described in this paper captured the planning phenomenon using the numerical analysis. The comparison with the Savitsky (1969) method revealed comparable results for Fn>1; within the smaller velocities range, the results are substantially different, due to the fact that planning phenomenon is considered to begin at Fn > 1-1.2, therefore the velocities corresponding to Fn less than 1 seems to be not accurately predicted by Savitsky (1969) method, thus leading to divergent results compared with the CFD solution, as shown in the Figures 9 and 10. The CFD numerical approach can offer information that help the improvement of the hull shapes, especially in the bow area for flow optimization in the preplanning phase. For the velocities 0.66 <Fn <0.99 it is shown that the flow of water has the tendency to climb on the semi tunnel extension above the waterline (figure 6), leading to an additional resistance and probably delaying the transition to planning regime. Further studies with a modified bow shape will be conducted in order to improve the spray shape and hull resistance.

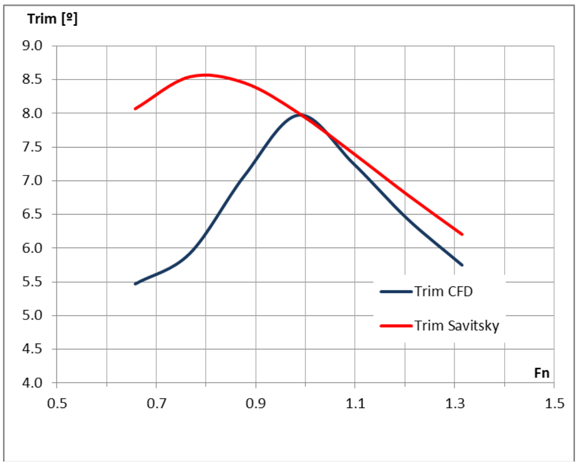


Fig. 9
Trim angle comparison

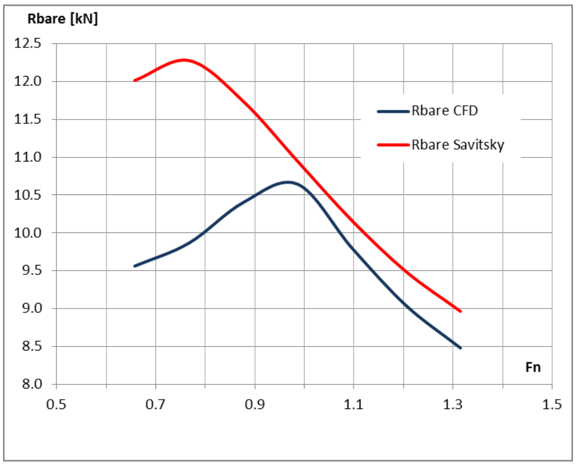


Fig. 10.
Bare hull resistance comparison

References

Azcueta, R. 2003. Steady and unsteady RANSE simulations for planning RAFTS. In *Proceedings of the 7th Conference on Fast Sea Transportation, FAST'03*.

Battistin, D.; Iafrati A. 2003. A numerical model for hydrodynamic of laning surfaces. In *Proceedings of the 7th Int. Corif. Fast Sea Transportation FAST 2003*.

Caponnetto, M. 2001. Practical CFD simu1ations for planing hulls. In *Proceedings of the Second International Euro Conference on High Performance Marine Vehicles*, 128-138.

Deng, G.B.; Queutey, P.; Visonneau, M. 2010. RANS Prediction of the KVLCC2 Tanker in Head Waves. In *Proceedings of the 9th International Conference on Hydrodynamics*.

Duvigneau, R.; Visonneau, M.; Deng, G.B. 2003. On the role played by turbulence closures in hull shape optimization at model and full scale, *Journal of Marine Science and Technology*, 8(1): 1-25.

Faltinsen, O.M. 2006. *Hydrodynamics of High-Speed Marine Vehicles*, Cambridge University Press, Cambridge, UK.

Su, Y.; Chen, Q.; Shen, H.; Lu, W. 2012. Numerical Simulation of a Planning Vessel at High Speed, *Journal of Marine Science and Application*, 11(2): 178-183.

Ghassemi, H.; Ghiasi, M. 2008. A combined method for the hydrodynamic characteristics of planning craft, *Ocean Engineering*, 35(3-4): 310322.

Queutey, P.; Visonneau, M. 2007. An interface capturing method for free-surface hydrodynamic flows, *Computers & Fluids*, 36(9): 1481-1510.

Savitsky, D. 1964. Hydrodynamic design of planing hulls, *Marine Technology*, 1(1): 71-95.

Wackers, J.; Visonneau, M. 2009. *Adaptive grid refinement for ship flow computation*, Proceedings of ADMOS 2009, Brussels, Belgium.

A STOPPING MANEUVER BASED APPROACH FOR CONFLICT SITUATION ASSESSMENTS ON THE RIVER DANUBE

Aleksandar Radonjić[1], Vladislav Maraš[2]
[1,2] University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia

Abstract: Due to introduction of River Information Services on the rivers of Serbia at the start of the 2014 it is possible to investigate collision-involved ships on the Danube river which is the most congested fairway in Serbia. The main interest in the fairway should be critical sectors where the waterways are busy and where the potential for the collisions is high. The study in this paper aims to evaluate the risk of potential collisions among ships in the river Danube and relies on the former studies in this scientific area. It also brings some new aspects characteristic for the river fairways and proposes new method for the calculation of the relationships among ship positions, ship speeds and ship conflicts.

Keywords: safe distance, conflict distance, collision distance, inland waterways.

1. Introduction

The inland waterway transport in Serbia plays a significant role in the transport of cargo to and from Serbian river ports, annually transporting from 2 to 6 million tons of goods (Strategy of the development of inland waterway transport, 2014). This transport is carried out by roughly 2.500 ships mostly consisted of push barges and self propelled barges owned by Serbian and foreign inland waterway transport companies and mainly companies with a small number of ships (Strategy of the development of inland waterway transport, 2014). Inland waterway transport decreased (in terms of tone-km) by over 50% from 1990 to 2011 in Republic of Serbia, but also increased by over 25% between 2012 and 2015. Given the increased transport over the road network in the last 25 years (from 1990 to 2015), it is expecting to open more opportunities for freight transport by barges and overall by inland waterway ships. Over the last three years (from 2012 to 2015) it is recorded more inland transportation units and self propelled barges of inland ships in Republic of Serbia (Statistical Office of the Republic of Serbia). It is also expecting increase in number of inland transportation units by 10.5% from 2012 to 2020 and by 34.4% from 2012 to 2025 (Strategy of the development of inland waterway transport, 2014).

Because of the increase of the transportation and the expectation of the increase of the transportation, traffic on the river fairways in Serbia is expected to grow from 2012 to 2025. It will bring the growth of the ship movements in the Serbian rivers and especially on the river Danube. Increased number of ship movements could open the possibility of the increased number of accidents among the ships (Yip, 2008 and Qu et al., 2011).

Serbian authorities responsible for the inland waterway transportation have already adopted River Information Services (RIS) that relies on Automatic Identification System (AIS) and Electronic Chart and Information Systems (ECDIS). Port authorities also rely on RIS. They have already experimented with the various safety systems that could help them avoid risks of different critical situations like collisions or grounding of the ships (Radonjic et al., 2007) and enable them safer navigation for the ships. The effectiveness of these experiments is under the question.

Lot of authors and researchers established various models and techniques for the navigational risk assessment over the past years. Great number of these models is based on the evaluation of the occurrence frequency of navigational accidents. However, navigational accidents cannot be evaluated only by occurrence frequency. They also depend on maneuverability of the ships involved in accidents for example. Therefore, the authors are concerned about the navigational accidents related to ship maneuverability in this paper.

The main attention in this paper is on the critical distance and the distance and area between critical distance and collision distance between two ships involved in navigational accident. Critical distance is defined as a measurement of distance between two vessels involved in navigational accident that are on collision course (Montewka et al., 2010).

It is of a crucial importance to regularly determine critical distance between two ships involved in navigational accident. The distance has to be correctly counted relying on the different factors that are already implemented in the navigation of ships. These factors include the type of fairways, special areas of the fairways where the congestion can be higher than in the other parts of fairway, the type of ships involved in navigational accidents, hydro-meteorological parameters, ship maneuverability, human behavior etc. The emphasis is put on the parameters which significantly contribute in turning critical distance to collision of ships in this paper. Parameters are then included in the process of determination of safe critical distance and safe critical time between two ships that are on the collision course.

The first isolated factor refers to a river or a sea fairways. In this paper only river fairways will be considered because the navigation of ships in the Republic Serbia takes place on the rivers. The example will be on the river Danube.

The second factor that contributes to safe critical distance is the ship maneuverability. Ship motions on the rivers are mostly forward except in the curvatures. Ships are sailing on the designed and marked fairways. In the waters out of the marked fairways there is no confirmation of the authorities that the navigation is safe. It indicates that every ship out of the labeled fairway could find itself in the danger of striding or could encounter stationary vessels and collide with them. Navigation rules also suggest that some ships in downstream navigation have a priority of the passages

[1] Corresponding author: a.radonjic@sf.bg.ac.rs

independently of the movement of the second ship included in the conflict situation for example. This is the reason why the influence of the stopping maneuver on the critical distance will be investigated in this paper.
The aim of this paper is to determine safe distance, conflict distance and collision distance on the basis of the calculations presented in (Mou et al., 2010) with added stopping distance maneuver. The aim is also to show that critical distance is very dependable on stopping maneuver. In the approach presented in this paper, it is assumed that a collision between two ships becomes reality when the distance between the ships is not enough to perform efficient stopping distance maneuver. The space and time required for a second ship to perform a stopping distance maneuver depends mostly on ship hydrodynamics and maneuverability features.
Safe distance is distance between ships' centers of gravity where the probability for the collision of two ships is equal to 0. Conflict distance is distance between ships' centers of gravity where the probability for the collision of two ships is between 0 and 1. Collision distance is distance between ships' centers of gravity where the probability for the collision of two ships is equal to 1. Safe distance, conflict distance and collision distance are presented graphically in Fig. 1.

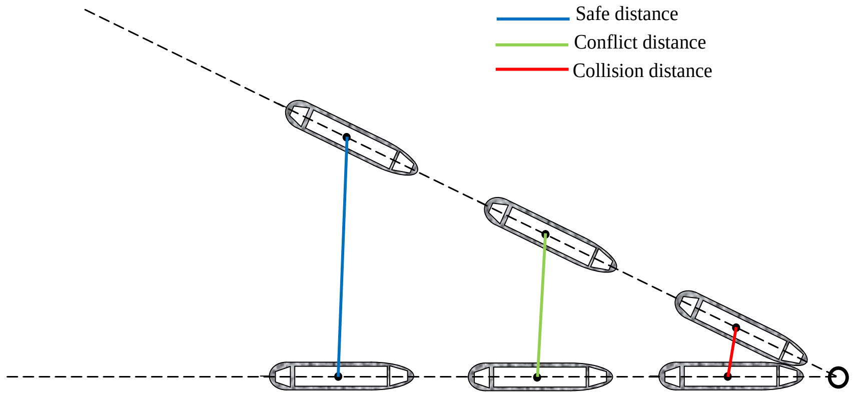


Fig. 1.
Safe distance, conflict distance and collision distance

Special attention is focused on conflict distance. Conflict distance is calculated by implementing ship stopping distance into the calculus.
Only one conflict situation is investigated. It is situation when the first ship has the right to pass without stopping according to navigational rules and therefore second ship is obliged to perform stopping maneuver. It is assumed that ships are navigating in deep water with the flow. Flow velocity is implemented in the final result. The minimum distance between two ships on collision course is conducted for self propelled barges, but is intended for all types of river ships in future work. Conflict situations are repeated for angles of course intersections from 11° to 60° which are the most frequent on the river Danube among all other traffic situations.
The entire estimation of the critical distance and collision distance is done with data transmitted from RIS and from ships.

2. Literature review

Many papers investigating ship collisions and critical distances have been presented in the recent years. Fujii's (Fujii et al., 1974) method rated as the most popular due to its simplicity. However, it didn't take into account ship dynamics and it assumes that a collision is on the track when two ships come to a distance defined as the collision diameter. Another approach based on the critical distance between two ships was applied to perform a risk analysis for a large suspension bridge by Pedersen (2002), in which the critical distance between two ships was assumed a constant value, and only head-on encounters were considered.
The other paper comes from Macduff (1974) and states that the number of ship conflicts multiplied by a causation probability. There are various mathematical models that propose to estimate the ship collision frequency such as from Tan and Otay (1999), Fowler (2000), Szlapczynski (2006) and Wang (2010).
Another group of papers related with navigational accidents make up computer simulation-based approaches and they quantitatively examine various navigational safety issues (Dand, 2001 and Zhang, 2006). The most recent paper in this scientific area is from Tian et al. (2017). The authors proposed quantitative risk assessment model which take into account the occurrence frequency and consequence of ship collisions. They made a collision frequency estimation model to evaluate the occurrence frequency of ships being involved in collisions.
Collision frequency estimation is more represented in the literature than mechanical models and simulation methods for collision consequence estimation. Servis and Samuelides (1999) paper refers to the finite element simulation of ship collisions. They proposed finite element technique for the assessment of the collision behavior of a ship under the defined collision scenario, for the relative comparison of structural arrangements and for the validation of analytical techniques for collision analysis.

The idea ship's maneuverability implementation into a collision assessment model was presented by Curtis (1986) for the first time. His model was restricted to one ship type with the overtaking and head-on maneuvers.
In 2010 (Montewka et al., 2010) presented a new approach for collision modeling probability which includes ship maneuverability. They used ship motion model to determine the minimum distance to collision for the waterways between Helsinki and Tallinn and for the summer traffic.
In the opinion of the authors there are very few papers that are dealing with the ship maneuverability as a factor that increase or decrease influence on navigational accidents. The contribution of this paper is in improvement of the existing models described in Mou et al. (2010) and Montewka. et al (2010) presented in Tian et al. (2017). Also, the model is formulated for the navigation on the rivers and can be used for river ships.

3. Model formulation

3.1. Definition of ship conflict (Assessment of minimum distance to collision)

According to Montewka et al. (2010) there are three conflict situations on the fairways based on the course difference of two ships:

1. Overtaking conflict where ships lye on almost the same courses and the course difference is not more than 10°,
2. Head-on conflicts in which two ships' courses differ in the range between 170° and 190°,
3. Crossing conflict in which the difference between ships' courses falls in the all other ranges not mentioned before from 0° to 360°.

Conflict distance on the river is the same as in the Montewka et al. (2010) with one crucial difference. It is determined on the base of ship motion in which one ship has the forward motion while other ship tries to cross over the first ships' forward course with the specified angle of course. In this paper ships' courses that differ in the range between 10° and 60° will be investigated. Other combinations of ships' course differences for crossing conflicts are not interesting because the major number of ship encounters on the river Danube falls in the specified ranges between 10° and 60°.
The following assumptions were made:

- Ships are navigating at full approach speed,
- The ships start their maneuvers according to variants described in introduction,
- The settings of the steering gear and propulsion during the maneuver are constant,
- The initial course of the first ship is always 0°,
- The initial course of the second ship is between 10° and 60°,
- Both ships stays on the initial courses,
- Only stopping distance maneuver is performed.

3.2. Definition of collision distance, conflict distance and safe distance

The collision between two ships becomes real when the distance between two ships is to low to perform efficient maneuvers to avoid collision (Montewka et al., 2010). Collision distance in this paper is the distance between two centers of gravity defined in a moment when two ships contact with their leftmost and rightmost points in the front of their hulls (see Fig. 1). Fig. 2 describes geometrically the collision distance.

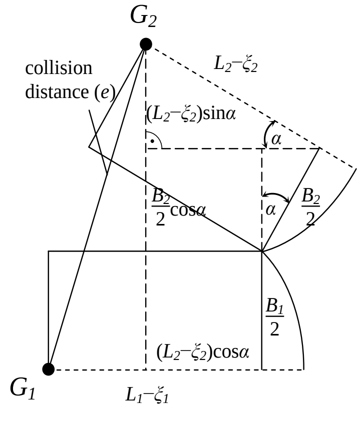


Fig. 2.
Geometrical presentation of collision distance

The main factors relevant to determine collision distance (e) are ships' length between perpendiculars (L), ships' beam (B), angle of intersection (α) and horizontal component of the center of gravity (ξ). From Fig. 2. collision distance (e) is:

$$e = \sqrt{\left[L_1 - \xi_1 - (L_2 - \xi_2)\cos\alpha + \frac{B_2}{2}\sin\alpha\right]^2 + \left[(L_2 - \xi_2)\sin\alpha + \frac{B_2}{2}\cos\alpha + \frac{B_1}{2}\right]^2} \quad (1)$$

Conflict distance is the distance between two centers of gravity defined in a moment when captain of the second ship can react in order to avoid collision with the first ship (see Fig. 1). Reaction is equal to necessary commands that are related to stopping maneuver in this paper. Fig. 3 describes geometrically the conflict distance.

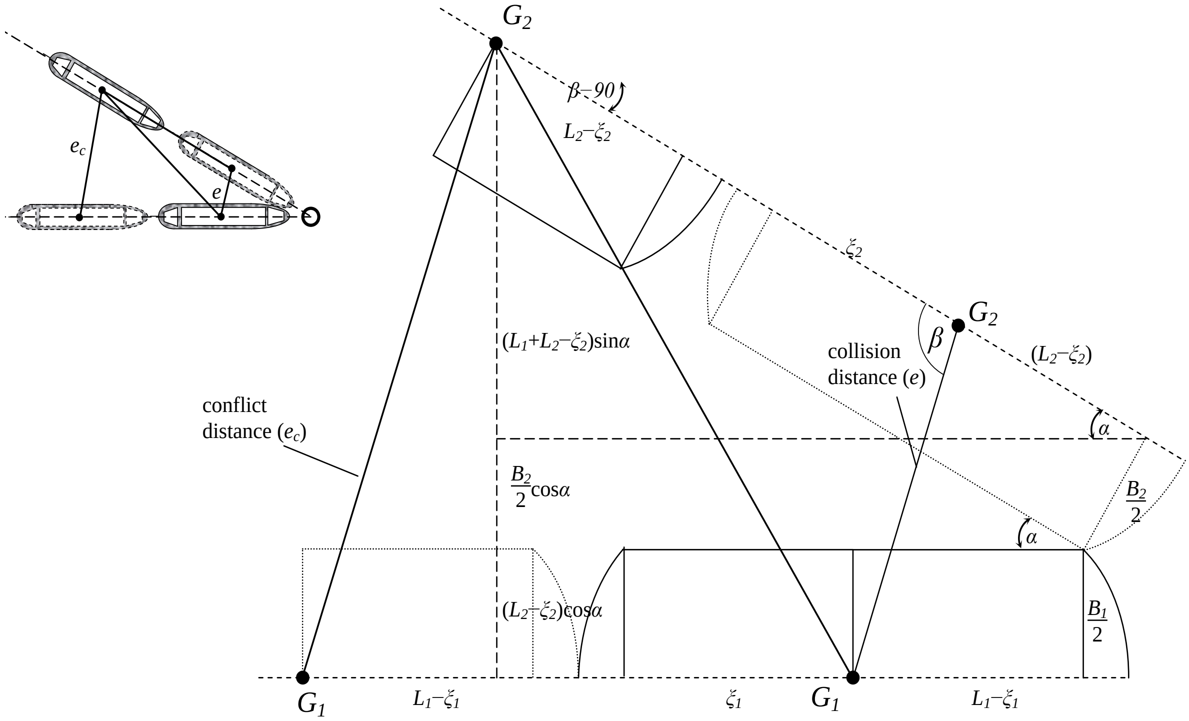


Fig. 3.
Geometrical presentation of conflict distance

If the two ships move with the same speeds and are not to collide the minimum horizontal difference between collision distance and conflict distance is equal to the length of the first ship (L_1). If the second ship is somewhere between collision distance and conflict distance on his path and course, the collision can be avoided if the captain of the second ship react in time enough to stop the ship with the stopping maneuver. Conflict distance and collision distance are presented in Fig. 3 with the parallel lines which is the condition that results from assumption that ships are navigating at full approach speed. From Fig. 3. conflict distance (e_c) is:

$$e_c = \sqrt{\left[2L_1 - \xi_1 - (L_2 - \xi_2)\cos\alpha + \frac{B_2}{2}\sin\alpha\right]^2 + \left[(L_1 + L_2 - \xi_2)\sin\alpha + \frac{B_2}{2}\cos\alpha + \frac{B_1}{2}\right]^2} \quad (2)$$

Safe distance is distance between two centers of gravity longer than conflict distance.

3.3. Stopping maneuver

A ships' stopping distance is estimated with the following formulae (IMO, 2003 and D'Arcangelo, 1957):

$$(m + m_x)\cdot\frac{du}{dt} = -T - R \quad (3)$$

Where; m: the ship mass, m_x: surge added mass, R: ship resistance, T: propeller thrust and u: ship speed.
Two basic assumptions are applied:

1) The ship's resistance is calculated according to (Basin et al., 1976 in Latorre et al., 1982, Kreculj and Colic 2008 and Zvonkov, 1956),

2) The propeller thrust is a linear function of distance the ship travels until an astern value of T_S is reached, after which the thrust remains constant (D'Arcangelo, 1957). This is illustrated in Fig. 4.

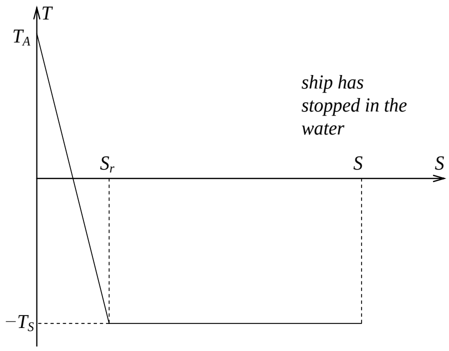


Fig. 4.
Assumed thrust acting on ship during stopping maneuver Source: (Varyani, 2009)

With these assumptions, the equation (1) is solved analytically and the stopping distance and stopping time are as follows (Varyani and Krishnankutty, 2009 and D'Arcangelo, 1957):

$$S = \frac{1}{2}u_o t_r + \frac{(m + m_x)\cdot u_o}{2R_o}\cdot \log_e\left(1 + \frac{R_o}{T_S}\right) \tag{4}$$

$$t = \frac{1}{2}t_r + \frac{(m + m_x)\cdot u_o}{g\cdot R_o}\cdot\left(\frac{R_o}{T_S}\right)^{1/2} \tag{5}$$

where t_r is the time at which the reverse thrust (T_S) is achieved, u_o, R_o, T_S are the approach speed, the resistance at approach speed and astern thrust respectively.

4. Numerical example (computational results)

Two self-propelled barges are used for numerical example. Their principal dimensions are:

L_1 = 74.80 m L_2 = 85.98 m
B_1 = 12.01 m B_2 = 8.44 m
d_1 = 0.58 d_2 = 0.68 m
m_1 = 355,800 kg m_2 = 384,900 kg

Computational results are shown in Table 1.

Table 1
Stopping time and stopping distance for the second ship

Ship speed u (km/h)	*Time required to achieve astern thrust. t_r (s)*	*Entire mass of the ship $m + m_x$ (t)*	*Propeller astern thrust. Ts (N)*	*Time to stop the ship after an astern value of T_S is reached. $t - t_r$ (s)*	*Stopping time. t (s)*	*Distance travelled by a ship slowing during time t_r. s_r (m)*	*Distance travelled by a ship slowing during time $t - t_r$. s_2 (m)*	*Stopping distance. s (m).*	*Time required to avoid collision (s)*
8.5	20	387.924	-6587.37	110.2746	130.275	23.61111	100.3157	123.927	31.68
9	20	387.924	-6611.86	114.3687	130.275	25	109.1659	134.166	29.92
9.5	20	387.924	-6636.78	118.2354	130.275	26.38889	118.0431	144.432	28.3453
10	20	387.924	-6662.18	121.8771	130.275	27.77778	126.9077	154.686	26.928
10.5	20	387.924	-6688.09	125.295	130.275	29.16667	135.7197	164.886	25.6457
11	20	387.924	-6714.57	128.4898	130.275	30.55556	144.4395	174.995	24.48
11.5	20	387.924	-6741.66	131.4616	130.275	31.94444	153.0276	184.972	23.4157

Ship speed u (km/h)	*Time required to achieve astern thrust. t_r (s)*	*Entire mass of the ship m + m_x (t)*	*Propeller astern thrust. Ts (N)*	*Time to stop the ship after an astern value of T_S is reached. $t - t_r$ (s)*	*Stopping time. t (s)*	*Distance travelled by a ship slowing during time t_r. s_r (m)*	*Distance travelled by a ship slowing during time $t - t_r$. s_2 (m)*	*Stopping distance. s (m).*	*Time required to avoid collision (s)*
12	20	387.924	-6769.42	134.2101	130.275	33.33333	161.4448	194.778	22.44
12.5	20	387.924	-6797.91	136.7349	130.275	34.72222	169.6528	204.375	21.5424
13	20	387.924	-6827.2	139.0355	130.275	36.11111	177.6143	213.725	20.7138
13.5	20	387.924	-6857.36	141.112	130.275	37.5	185.2937	222.794	19.9467
14	20	387.924	-6888.48	142.9643	130.275	38.88889	192.6572	231.546	19.2343
14.5	20	387.924	-6920.65	144.5931	130.275	40.27778	199.6733	239.951	18.5710
15	20	387.924	-6953.97	145.9997	130.275	41.66667	206.3133	247.980	17.952
15.5	20	387.924	-6988.56	147.1858	130.275	43.05556	212.5516	255.607	17.3729
16	20	387.924	-7024.54	148.154	130.275	44.44444	218.3661	262.810	16.83
16.5	20	387.924	-7062.06	148.9073	130.275	45.83333	223.7381	269.571	16.32
17	20	387.924	-7101.29	149.4497	130.275	47.22222	228.6527	275.875	15.84
17.5	20	387.924	-7142.42	149.7856	130.275	48.61111	233.099	281.710	15.3874

According to Table 1 time required to achieve astern thrust is 20 seconds. This time is average value from Olshamovskeih et al. (1979). The length of the first ship is 74.8 m which means that second ship has to late about 15.39 seconds to 31.68 seconds depending on the ship speed between 8.5 km/h to 17.5 km/h. It is calculated that even if the second ship react immediately she can enter the collision distance depending on the speed of the ships in the moment before stopping maneuver. Entering the collision distance starts to appear when the ship speed is 11.5 km/h. As the angle between two ships increases the critical ship speed increases and at about 29º to 60º conflict distance according to formula **Error! Reference source not found.Error! Reference source not found.** can be considered as the right moment to start stopping distance maneuver. At angles bellow 29º if the second ship react immediately after entering the conflict distance she will not be able to avoid collision with the first ship with the higher speeds.

5. Conclusion

In this paper stopping distance based approach for conflict situation assessments on the river Danube is proposed. Authors tried to improve previous works related to conflict distances and collision distances and to set previous models and methods to the river Danube traffic. Critical distances in this paper between two ships on collision courses are conducted for self propelled barges. Other ship types plan to be implemented in future work.
Firstly, safe distance, conflict distance and collision distance are defined. Then, stopping maneuver is proposed to implement in the calculation of distance to avoid collision. After already obtained results by numerical example it is concluded that second ship can avoid collision if start to stop at the point where conflict distance began. However, for the angles of course intersections bellow 29º conflict distance has to be recalculated as the second ship cannot avoid collision even if react at the time proposed in the paper. Question remains what is the safe time for the second ship to start with stopping distance maneuver for the angles bellow 29º.
It was proved that proposed calculus can be applied on self-propelled barges and on other river ships. There is also advantage of the proposed calculus when there is not enough information about the accidents on the river Danube as it is based on stopping distance maneuver.
As a next step, the authors are studying the impact of changes in the numerical example when self-propelled barges are replaced with barge convoys. Also, there is some conflict situation where river ships can perform turning maneuver to avoid collision and this maneuver can be added to numerical example.

References

Basin, A.M.; Velednitsky, I.O.; Lyakhovitsky, A.G. 1976. Ship Haydrodynamics in Shallow Water, *Sudostroeniye*, Leningrad, 37: 266-275.
Curtis R. 1986. A ship collision model for overtaking, *Journal of Navigation*, 37(04): 397-406.
D'Arcangelo, A.M. 1957. *Guide to the selection of braking power*, Technical Research Bulletin, No.3-5, The Society of Naval Architects and Marine Engineers (SNAME).
Dand, I.W. 2001. Approach channel design: the PIANC approach. In *Proceedings of the International Workshop on Channel Design and Vessel Maneuverability*, 45-49

Fowler, T.G.; Sorgard, E. 2000. Modeling ship transportation risk, *Risk Analysis*, 20: 225-244.

Fujii, Y.; Yamanouchi, H.; Mizuki, N. 1974. Some factors affecting the frequency of accidents in marine traffic—the probability of stranding and the effect of darkness on the probability of collision and stranding, *Journal of Navigation*, 27: 239-47.

IMO 2003. *Revision Of The Explanatory Notes To The Standards For Ship Manoeuvrability*, SUB-COMMITTEE ON SHIP DESIGN AND EQUIPMENT.

Kreculj, D.; Colic, V. 2008. *Navigable equipments*. University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia.

Latorre R.; Luthra G.; Tang, K. 1982. Improvement of inland waterway vessel and barge tow performance: Translations of Selected Chinese, German and Russian Technical Articles, Report 249, The University of Michigan College of Engineering, Ann Arbor, U.S.A.

Macduff, T. 1974. Probability of vessel collisions, *Ocean Industry*, 9(9): 144-148.

Montewka, J.; Hinz, T.; Kujala, P.; Matusiak, J. 2010. Probability modeling of vessel collisions, *Reliability Engineering and System Safety*, 95: 573-589.

Mou, J.M.; Tak, C.; Ligteringen, H. 2010. Study on collision avoidance in busy waterways by using AIS data, *Ocean Engineering*, 37: 483-490.

Olshamovskeih, S.B.; Zemlyanovskeih, D.K.; Shyehpyehtov, I.A. 1979. *Organezaceya byehzopasnoste plavaneya sudov (Safety of ship navigation)*. Transport, Moscow, Russia.

Pedersen, P. 2002. Collision risk for fixed offshore structures close to high-density shipping lanes, *Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment*, 216(1): 29-44.

Qu, X.; Meng, Q.; Li, S. 2011. Ship collision risk assessment for the Singapore Strait, *Accident Analysis and Prevention*, 43: 2030-2036.

Radonjic, A.; Hrle, Z.; Avramovic, Z. 2007. *New Location Based System Built Upon Geographic Information System*, In European Inland Waterway Navigation System, EIWN 2007, Visegrad, Hungary.

Servis, D.P.; Samuelides, M. 1999. Ship collision analysis using finite elements. In: SAFER EURORO Spring Meeting.

Statistical Office of the Republic of Serbia 2015, *Transport and Communication in Republic of Serbia*, *2014*, No. 606.

Ministry of Construction, Transport and Infrastructure, Republic of Serbia 2014. Strategy of the development of inland waterway transport in Republic of Serbia from 2015 to 2025. Available from Internet: http://www.mgsi.gov.rs/sites/default/files/Strategija razvoja vodnog saobraćaja Republike Srbije od 2015. do 2025. godine _0.pdf.

Szlapczynski, R. 2006. A unified measure of collision risk derived from the concept of a ship domain, *Journal of Navigation*, 59: 477-490.

Tan, B.; Otay, E.N. 1999. Modeling and analysis of vessel casualties resulting from tanker traffic through narrow waterways, *Naval Research Logistics*, 46: 871–892.

Tian, C., Jinxian, W., De-qi, X. 2017. Development of a quantitative risk assessment model for ship collisions in fairways, *Safety Science*, 91: 71-83.

Varyani, K.; Krishnankutty, P. 2009. Stopping manoeuvre of high speed vessels fitted with screw and waterjet propulsion, *Journal of Marine Engineering & Technology*, 8(1): 11-19.

Wang, N. 2010. An intelligent spatial collision risk based on the quaternion ship domain, *Journal of Navigation*, 63: 733–749.

Zhang, H.; Huang, S. 2006. Dynamic control of intention priorities of human-like agents. In *Proceedings of the 17th European Conference on Artificial Intelligence*, ECAT 2006.

Zvonkov, V.V. 1956. *Ship resistance calculations*, River Transport, Moscow, Russian.

Yip, T.L. 2008. Port traffic risks – a study of accidents in Hong Kong waters, *Transportation Research Part E: Logistics and Transportation Review*, 44: 921-931.

THEORETICAL APPROACH FOR FINANCING QUESTION OF FERRYBOATS: A CASE STUDY IN HUNGARY

Adam Torok[1]

[1] BME – Budapest University of Technology and Economics, Department of Transport Technology and Economics, Budapest, Hungary

Abstract: Nowadays infrastructure development and maintenance needs governmental financial support. In this paper the financing question of ferryboats are investigated in Hungary. In Hungary ferryboats are fundamental part of transport infrastructure, where river crossing is essential but no bridge were being built. In this paper author has investigated the phenomena and designed a theoretical method in order to scientifically ground the financial support of ferryboats in Hungary. There is a very strong constrain from political side. That is the maximum available financial resource. Therefore the model needs to distribute the available financial support taking into consideration social, economic and technical parameters. Author have designed a multi-criteria decision support tool in MS-Excel in order to be able to find the optimal solution of distribution of financial resources.

Keywords: ferryboat, finance, multi-criteria, assignment.

1. Introduction – Importance of ferry boats

Nowadays infrastructure development and maintenance needs governmental financial support it cannot be financed from market directly (Škrinjar, et al., 2015). In this paper the financing question of ferryboats are investigated in Hungary in 2014 and 2015. In Hungary ferryboats are fundamental part of transport infrastructure – Hungary has more than 60 ferryboat services (like Fig. 1.) on rivers and lakes -, where river or lake crossing is essential but no bridge were being built. Ferryboats also providing element support on intercity public transport (Černý et al., 2014) that is financed by government in Hungary.

Fig. 1.
Ferryboat on Tisza
Source: http://network.hu/babairen/kepek/irenke_fotoi/tiszai_komp

In this paper author has investigated the phenomena and designed a theoretical method in order to scientifically ground the financial support of ferryboats in Hungary. As public transport needs to be financed by the government and public financial resources are limited (Gaal et. al., 2015) a distribution and assigning strategy were needed. In previous years the financing support were distributed in equally or in case of distortion the cause were not scientifically clarified. Therefore in this paper author propose a multi-criteria model for scientific distribution of limited financial support between ferryboats based on their performance, role in infrastructure, or avoidance of emission due to the shorter way of transport (Toşa et. al., 2015; Ivković et. al., 2016). The hypothesis were that **ferryboats are playing important role in transport** of Hungary **based on their** network location and **performance and their maintenance and development needs to be financed** but not equally **therefore a scientifically grounded method needs to be built**.

[1] Corresponding author: atorok@kgazd.bme.hu

2. Methodology

Nowadays in Hungary 61 ferryboats are operational, from these 26 on Danube, 20 on Tisza, 6 on Bodrog, 3 on Szamoson, 2 on Kőrös, 2 on Sajó, 1 on lake Balaton and finally 1 on lake Velence are located. Ministry of National Develoment is responsible for Transport and has provided data as location of ferryboats, type of ferryboats, maximum carrying capacity of ferryboats (Fig. 2a., Fig. 2b., Fig. 2c.), role in network (temporary or permanent) and role in the region (connects national or regional or local roads and areas). The operation of these ferryboats saves time, energy and harmful emission on national level (Masoumi and Soltanzadeh, 2014).

Fig. 2a.
Ferryboat with maximum carrying capacity 150 t
Source: http://hu.wikipedia.org/wiki/Mohácsi_komp

Fig. 2b.
Ferryboat with maximum carrying capacity 50 t
Source: http://www.pakspress.hu/index.php?ugras=hirolvaso&hirszama=57809

Fig. 2c.
Ferryboat with maximum carrying capacity 10-20 t
Source: http://www.geocaching.hu/caches.geo?id=4012

Ministry also provided traffic data as ratio of work and non-work related traffic and hourly traffic volume as lorries, as passenger cars and as persons. In order to get more precise info on role of ferry boats in the network the length of detour were calculated as if the ferryboat were not existed in order to later estimate the social benefits of ferryboats (travel time shortage and emission reduction). Based on the provided and collected data a consistent database were conducted (Cserháti and Csizsár, 2016) coherent with accepted practice as a suitable solid basis of multi-criteria decision support tool. For this the criteria were weighted based on the consultation with experts of Ministry as follows (Fig. 3.):

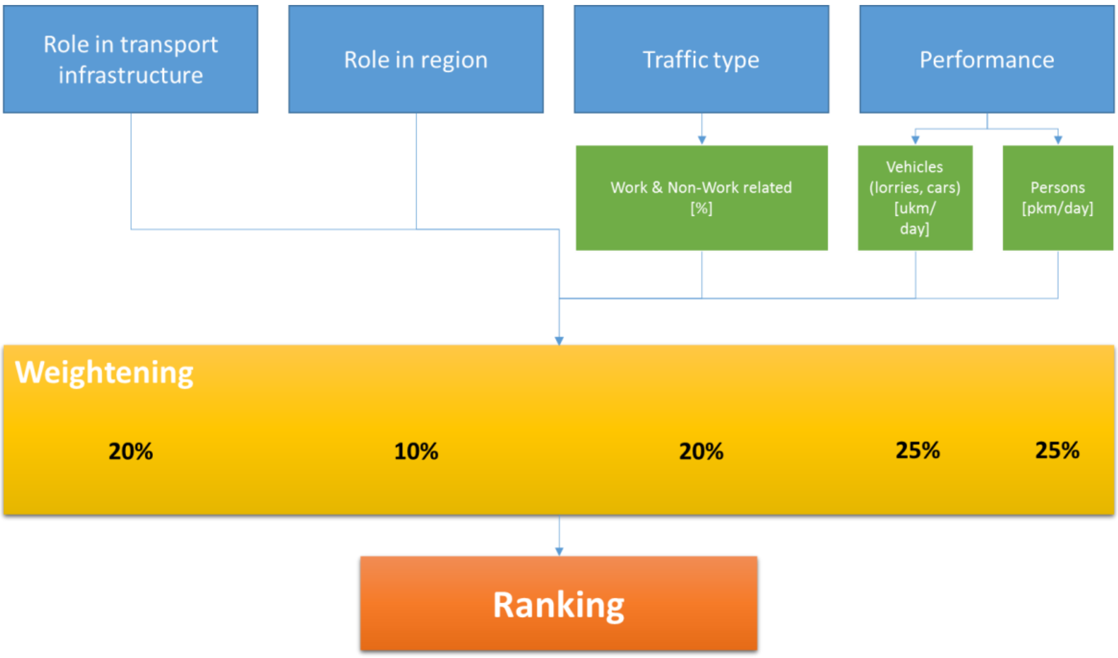


Fig. 3.
Concept of decision support tool
Source: own compilation

The monetary value of emission and fuel consumption reduction were calculated based on (1):

$$C_{fuel} = \left(\sum_{i=1}^{m} e_i \cdot d \right) \cdot v_j \quad (1)$$

Where; C_{fuel}: Private cost of fuel consumption surplus [HUF], e_i: fuel consumption of vehicle i [litre/100 km] based on the statistical value of Hungarian vehicle fleet consumption analysis, d: estimated distance of detour [km], v_j: cost factor of fuel j [HUF/litre] (Meszaros and Torok, 2014)

The monetary value of travel time saving were calculated based on (2):

$$TTS = \left(\sum_{j=1}^{n} N_j \cdot \Delta TT\right) \cdot \tau \tag{2}$$

Where; TTS: Monetary value if travel time saving [HUF], Nj: Number of passengers and vehicles, ΔTT: Change in travel time [hour] – please note that it is surely positive in case of closure of ferryboats, τ: Monetary value of travel time [HUF/h] (Meszaros and Torok, 2014).

3. Results

Based on the traffic circumstances and calculated length of detour author could determine the external revenue of ferryboats based on the travel time shortage on not to use the detour and decrease of emission. Based on their performance and their role on network with the help multi-criteria decision support tool the ranked list of ferryboats and their governmental financial support could be generated. Not only the ranking could be done but also could be investigated the result of closure of any ferryboats as concluded in *Table 1*:

Table 1
External revenue of ferryboats

Component	Value [EUR]
Monetary value of Travel Time Shortage	41 500
Monetary value of emission reduction	535 500

Source: own compilation

4. Conclusion

In this paper a multi-criteria tool is being introduced that not only capable of ranking by the limit financial support of national funds on ferryboats but also capable of estimating the external revenues and loses of ferryboats whenever their operation is maintained or whenever they are closed. With this decision support tool the political decision maker can rank the ferryboats and can decide their limited financial support. Great disadvantage of the tool that needs that data updated on yearly bases. Even closure of one ferryboats could have effect on the whole system as could influence the detour length and therefore the external revenues. Later author plan to develop the model and extend with assignment module in order to be able assess development project separately. Ferryboats are playing important role in transport of Hungary as it can be seen. Based on their network location and performance their maintenance and development push different obligation to government or local authority. Therefore their differentiated finance need to be solved on a solid scientific ground.

Acknowledgements

Author is deeply acknowledge the support of Arpad TOTH former head of division of Transport policy and Economics in KTI – Institute for Transport Sciences, and help of Eva MESZAROS. Also grateful thanks for all experts in Ministry of National Development for their valuable comments.

References

Černý, J.; Černá, A.; Linda, B. 2014. Support of decision-making on economic and social sustainability of public transport, *Transport*, 29(1): 59-68.

Cserháti, B.; Csiszár, Cs. 2016 Conception of Personalized Parking Assistant Application, *Periodica Polytechnica-Civil Engineering*, 60(2): 181-188.

Gaal, Gy.; Horváth, E.; Török, Á.; Csete, M. 2015. Analysis of Public Transport Performance in Budapest, Hungary, *Periodica Polytechnica Social and Management Sciences*, 23(1): 68-72.

Ivković, I.; Čokorilo, O.; Kaplanović, S. 2016. The estimation of GHG emission costs in road and air transport sector: Case study of Serbia, *Transport*, in Press, doi: 10.3846/16484142.2016.1169557

Masoumi, H.E.; Soltanzadeh, H. 2014. A Regional Analysis Of Urban Population And Transport Energy Consumption, *International Journal for Traffic & Transport Engineering*, 4(4): 372-385.

Meszaros, F.; Torok, A. 2014. Theoretical Investigation of Emission and Delay Based Intersection Controlling and Synchronising in Budapest, *Periodica Polytechnica Transportation Engineering*, 42(1): 37-42.

Škrinjar, J. P.; Abramović, B.; Brnjac, N. 2015. The Use Of Game Theory In Urban Transport Planning, *Tehnicki vjesnik/Technical Gazette*, 22(6): 1617-1621.

Toşa C.; Antov D.; Köllő G.; Rõuk H.; Rannala, M. 2015. A methodology for modelling traffic related emissions in suburban areas, *Transport*, 30(1): 80-87.

SESSION 5: MARITIME TRANSPORT AND PORTS RESEARCH

MARITIME PASSENGER TRANSPORT IN THE ADRIATIC-IONIAN REGION

Maja Stojaković[1], Boštjan Žlak[2], Marina Zanne[3], Elen Twrdy[4]

[1,2,3,4] *Faculty of Maritime studies and transport, Portorož, Slovenia*

Abstract: Maritime passenger transport represents one of the most important modes of passenger transport in Europe. In 2013, the total number of passengers passing through EU-28 ports reached 400 million, which was a 0.5% increase over the previous year. The Adriatic-Ionian region, for one, is gaining importance within Europe with almost five million cruise passengers and seventeen million ferry passengers in 2013. Based on the data gathered through the EA SEA-WAY project, we have prepared an overview of the current state of cruise and ferry passenger traffic in the Adriatic-Ionian region, identified ports holding the largest traffic shares and presented guidelines for the future development of maritime passenger traffic within the region.

Keywords: maritime passenger transport, cruise traffic, ferry traffic, Adriatic-Ionian region.

1. Introduction

Recently, maritime passenger transport has become one of the most important modes of passenger transport in Europe. We can attribute this to its positive ecological and economic impact and to important stimulating actions taken by the European Union. Maritime passenger transport is composed of cruise transport and non-cruise transport, represented by ferry transport (EUROSTAT, 2015).
In 2013, the total number of passengers passing through EU-28 ports reached 400 million, which was a 0.5% increase over the previous year. Ferry lines transported the majority of passengers, while only 3.4% belonged to cruise shipping. Europe represents an extremely ferry intensive market, which is divided into two main ones - Northern Europe, including the Baltic, and all of the Mediterranean (EUROSTAT, 2015). In 2013, ferry ships in the Mediterranean region transported roughly 460 million passengers and 37 million cars. There is a dense network of ferry routes around the coasts of Italy, the Balkan states, the Greek Islands and between the Balearics and the mainland, with many of the ports offering services for 5 to 10 million (or even more) passengers per year.
According to Wergeland (Wergeland, 2012), the domestic market in Greece, with all the traffic among the myriad islands, represents one of the world's largest ferry markets and one of the main for the Adriatic.
Although cruise shipping represented only 3.4% of the passengers in EU-28 ports in 2013, this segment became a very important component of the maritime and tourism sector of the small number of ports and countries where it is concentrated. In 2013 there were 21.3 million cruise passengers, 51% coming from the USA (51%), while 30% originated from European countries (Cruise Lines International Association). More than 80% of the total number of cruise passengers embarking and disembarking in European ports did so in Italy, Spain, the United Kingdom and Germany. In the cruise sector, the Mediterranean represents one of the key regions in the world with a 21.7% share of passengers, second only to the Caribbean (34.4%). The Mediterranean cruise market can be divided into four major sub-regions, the western Mediterranean, the Adriatic, the eastern Mediterranean and the Black Sea. In 2013, the Adriatic sub-region ranked second, immediately after the western Mediterranean with a 22.3% market share.
The Adratic-Ionian region consists of about 20 ports that are engaged in cruise shipping and around 40 ports that perform ferry transport and has great growth potential. As can be seen from Figure 1 the maritime passenger transport is quite dense in this zone.

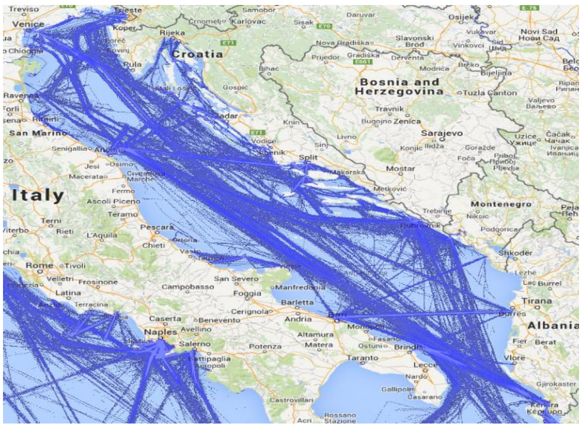


Fig. 1.
Passenger shipping in Adriatic-Ionian region
Source: (Marine traffic, 2014)

[1] Corresponding author: maja.stojakovic@fpp.uni-lj.si

There were over than 5.2 million cruise passenger movements in 2013, which is an increase of 4.6% compared to 2012 and approximately 17 million ferry passengers, a drop of 0.9% attributable mainly to the construction of new bridges and the consequent closure of some ferry links. Nevertheless, predictions suggest growth in both sectors in the coming years (Turismo, 2014).
This paper presents an overview of the most important cruise and ferry ports in the Adriatic–Ionian region, determines their competitive position in the region through port portfolio analysis and presents the potential for their development in the future.

2. Adriatic – Ionian cruise sector

The Adriatic sub-region is the second most important in the Mediterranean, immediately after the western Mediterranean. The number of passengers carried by cruisers in the Adriatic Sea steadily increased from 2009 to 2013. In 2009, the number of passenger visits reached 3.7 million, while in 2013 it reached 5.2 million, an increase of almost 40%. The number of cruise calls in the Adriatic ports also increased over this period. In 2009, there were 2,919 cruise ship calls, while in 2013 this number was 3,219, a growth of 10.28% (MedCruise, 2014a).
In 2013, the number of passengers in Adriatic ports increased by 6.2% over 2012, although the number of calls in the region decreased by 0.5% in the same year. These numbers represent a share of 19% of the total passenger visits to the Mediterranean region in 2013 and 22.3% of the cruise calls that took place in the Mediterranean ports (MedCruise, 2014b).
Despite the fact that in 2013 Adriatic ports received fewer ships than in 2012 this fact did not adversely affect the total number of passengers carried, implying that carriers using bigger ships, especially in larger ports. According to the traffic forecasts, there is a strong possibility that such trends will continue into the future. Ports will therefore have to optimize their existing port facilities, where necessary, so they will be able to receive larger ships.
The two countries that have leading roles in the Adriatic cruise market are Italy and Croatia, accounting in 2013 for approximately 80% of total cruise passengers.

Table 1
Cruise Traffic by Country, Absolute values and Shares percentage, 2013

Ports	**2013**		**Share of total (%)**		**2012**		**Variation on 2012 (%)**	
Country	Pax. mov	Calls	Pax. mov	Calls	Pax. mov	Calls	Pax. mov	Calls
Italy	2,702,789	912	51.8	28.6	2,691,415	1,074	0.4	-15.1
Croatia	1,381,572	1,332	26.5	41.7	1,326,955	1,365	4.1	-2.4
Greece	749,301	494	14.3	15,5	657,591	489	13.9	1.0
Montenegro	317,746	387	6.1	12.1	246,623	343	28.8	12.8
Slovenia	67,588	66	1.3	2.1	65,616	56	3	17.9
Albania	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a	n.a.
Bosnia-Herzegovina	0	0	0	0	0	0	0	0
Total 2013	5,218,996	3,191	100	100	4,988,200	3,327	4.6	-4.1

Source: Adriatic Sea Tourism Report 2014

Italy registered the highest number (2,702,789) of tourists on cruises in the Adriatic Sea in 2013, a 51.79% market share. Croatia was next with a 26.47% share and 1,381,572 tourists, and Greece, included though it is not in the Adriatic, was third, with a 14.36% share. Slovenia had quite a small (1.29%) share, which is to be expected for it has just one port (Turismo, 2014).
Both leading countries recorded smaller numbers of incoming cruisers in 2013 (Italy -15.1%; Croatia -2.4%). According to the Adriatic Sea Tourism Report, the reason for such a drop in Italy was mainly the reduced number of cruise calls to the main Italian ports. A similar situation occurred in certain Croatian ports, while the country with the highest growth in ship calls was Slovenia.

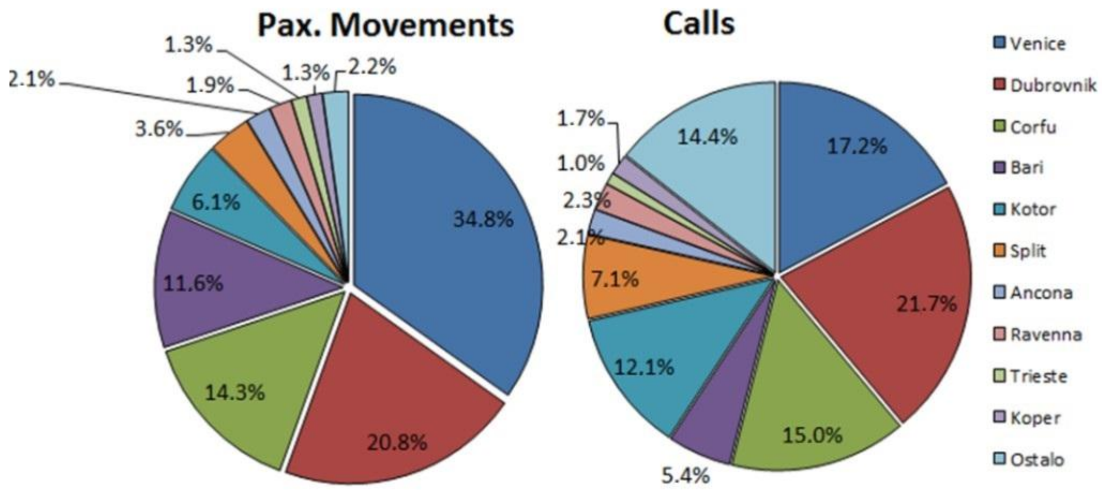


Fig. 2.
Traffic Share of the First 10 Cruise Destinations Among Adriatic Ports (2013)
Source: Adopted from the Adriatic Sea Tourism Report 2014

Figure 1 presents traffic shares regarding passenger movements and cruise calls of ten major cruise ports in the Adriatic. Venice and Dubrovnik, ranked first and second, together recorded half of all passenger movements in the Adriatic region (Venice 34.8%, Dubrovnik 20.8%).
According to the Adriatic Sea Tourism Report, in the next year the number of cruise passengers and cruise ship calls to the major Adriatic ports is expected to decrease. Traffic in Venice is expected to decrease by 7%, which is mainly attributable to restrictions regarding the acceptance of larger ships that were adopted in 2013. Meanwhile, Dubrovnik and Corfu are forecasted to have a 17% and 15% decrease, respectively. The main reason is in passenger distribution changes; that is, the increase of passenger movements towards ports that until now have previously been less visited. Smaller ports will therefore have more opportunities to attract passengers from larger ports. As Venice is considered the biggest attraction in the Adriatic, small ports will have major opportunities to attract passengers and large cruise ships if they have good terminal facilities in the proximity of Venice, as from those locations inland trips to the city of Venice can easily be organized.
For further analysis of the Adriatic region, nine Adriatic cruise ports that were included in the EA SEA-WAY project were selected, together with the port of Venice, as it is the main Adriatic cruise port.

2.1. Analysis of the selected cruise ports in the Adriatic-Ionian region

The study conducted within the EA SEA-WAY project included the Albanian port of Sarande, the Greek port of Igoumenitsa, the Italian ports, Ancona, Bari, Chioggia, Ravenna, and Trieste, along with the Slovenian port of Koper.
According to J.Corres (Corres and Papapchristou, 2013) and B. Lekakou (Lekakou et all., 2009) cruise ports can be divided into three classes with attendant subclasses. This includes hub ports (classes I, II and III), hybrid ports (classes A, B and C) and destination ports (classes 1, 2 and 3). A hub port serves as a homeport, meaning that it has the entire infrastructure required for embarkation or disembarkation of passengers and a place where passengers may begin or end their journeys. On the other hand, a destination port serves only as a port of call, a port where a ship only visits for a short period of time (often just for a few hours), but doesn´t provide services related to embarking/disembarking. Passengers at these ports don´t begin or end their journeys. The hybrid port is considered a hub port and a destination port at the same time. These ports usually have perfect conditions for embarking and disembarking including great hinterland connections by road, rail and particularly air.
Figure 3 clearly shows the two ports that receive the most passengers (Venice and Dubrovnik), which also top of the list in number of calls (Venice 548 and Dubrovnik 843, respectively). Although Dubrovnik has more calls, the ships tend to be smaller, carrying fewer passengers. Most likely, due to exceptional air and rail connections, Venice is classified as Hybrid A, while we can consider Dubrovnik as a destination port class 1, as the homeport operations are still too few for it to be considered a hybrid port. The two ports are both world-renowned destinations, UNESCO World heritage sites and thus major tourist attractions.

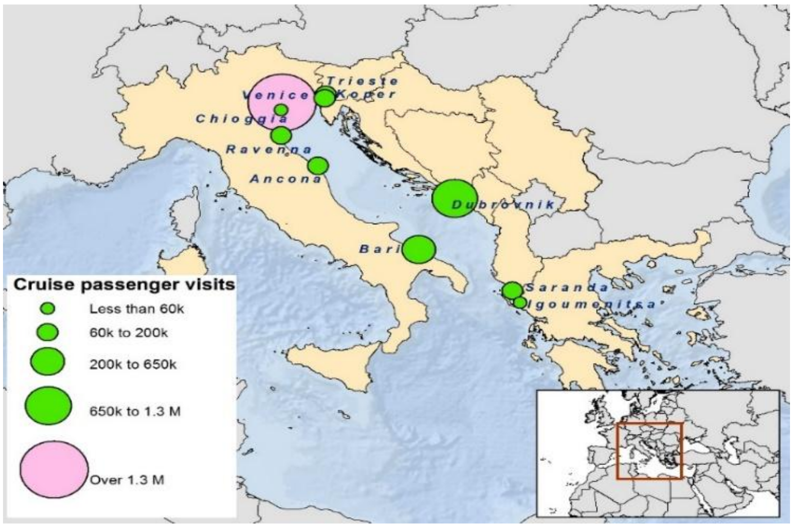


Fig. 3.
Cruise Passenger Visits, Adriatic-Ionian Region, 2013
Source: Adopted from the MedCruise, 2014

According to Lekakou (Lekakou et al., 2009)**,** the most important factors that affect the choice of ports to be included in a cruise line's itinerary are: port services to cruise ships, natural port characteristics, port services to passengers, port infrastructure, attractive touristic areas and activities, port service cost, port efficiency, port management, provision of intermodal transport, political conditions and regulatory framework, city amenities, and proximity to markets for cruise passengers. An important role in port choice is attributed to the port hinterland connections within the region. The vicinity of an airport proved to be one of the most important factors.

Fig. 4.
Airports In the Vicinity of Venice, Trieste and Dubrovnik
Source: Adapted from google maps

Venice fulfils all of these conditions and is considered the most important cruise port of the Adriatic-Ionian region. As shown in Figure 4, Venice also has the best air connections among the analysed ports. Not only does it have two international airports in the near vicinity, two more airports are available within less than an hour's drive. A valid alternative to the port of Venice is the port of Trieste, which is already gaining importance. The local cultural attractions and the proximity to its local airport, and especially to Venice, are reasons for its continuous development as a hybrid port. The port of Dubrovnik is the second most visited destination of the Adriatic-Ionian region and its status could even improve in the future as it represents a great tourist attraction. It is connected to one international airport.

2.2. Portfolio analysis of the selected Adriatic-Ionian cruise ports

To determine the competitive position of the analysed cruise ports, we used a rather simplistic approach with the "port portfolio analysis". It is usually used as a tool in strategic positioning analysis and offers a graphical representation of results within a "growth-share" matrix (Bagis and Dooms, 2014) for a certain timeframe.
The results in the matrix are based on annual growth rate data gathered from port websites and calculated average market share. Each of the matrix quadrants represent a port's role in the cruise market for the observed time span, based on their average market share and average annual growth, and the quadrants were determined by the average of all the ports' annual growth (12.1%) and average market share (10%). The ports have recorded rather large fluctuations of passengers in recent years; therefore, it is unlikely that the time span we used for observations is sufficient. Some of the analysed ports are in the early stages of their cruise destination development, lines established just a few years ago (e.g., Igoumenitsa, with almost no market share is thus not visible in the matrix). The cruise terminal in the port of Ravenna

was built in 2010 and within two years received cruise passenger traffic of more than 150,000 passengers, declining over the next two years to what seems will be a stable 100,000 passengers yearly.
Data in the matrix (Fig. 5) shows that the majority of the ports have a rather small market share (figures by the ports represent market share among selected ports) in comparison to the three ports with the most traffic.

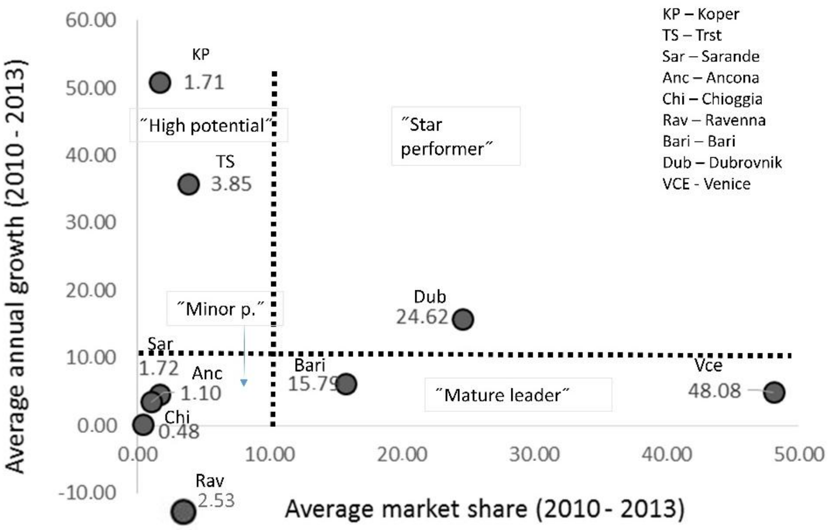


Fig. 5.
Port portfolio analysis
Source: Own calculations

It is important to note that the research was limited to the ports included within EA SEA-WAY project. Naturally, the position of the ports may change within the matrix if we included all the ports of the Adriatic-Ionian region; however, the matrix still represents a good overview of their competitive position and market share. The port of Venice clearly stands out from the rest of the ports with its position well into the ˝Mature leader˝ quadrant with almost 50% market share. This result is consistent with a similar study (Bagis and Dooms, 2014) among Mediterranean ports, which placed the port of Venice in the ˝star performer˝ quadrant for the period (2006-2011). The port of Bari is well situated in the mature leader quadrant with a steady market share and levelled passenger figures. Among the selected ports, only Dubrovnik is placed in the star performer quadrant. Its large market share, substantial average growth and the fact that it recently became a homeport, suggests that it will continue its trend of increasing passenger figures and further increase its market share. In the ˝High potential´ quadrant, Trieste stands out. Even though the port of Koper is situated in the same quadrant, the port of Trieste has greater potential to further its growth and strengthen its position in the quadrant and perhaps even move to the star performer quadrant due to its development as a hub/hybrid port. The minor performer quadrant is occupied by ports that are in various stages of their development with their futures unclear at this point.

3. Adriatic – Ionian Ferry sector

The geography of the Adriatic-Ionian region provides potential for the development of cross-sea ferry connections, especially from Italy towards Croatia, Montenegro, Albania and Greece, and for fast speed craft lines in the northern Adriatic; however, the majority of ports in the Adriatic-Ionian region have lost a number of ferry passengers in recent years (the trends are inconclusive and the drop in number of passengers is especially visible in 2013 in comparison to 2012).
There were around 17 million ferry passengers in 2013 in the Adriatic-Ionian region with the majority of them using domestic ferry lines in Croatia and Greece (Adopted from the Adriatic Sea Tourism Report 2014 (Turismo, 2014)).
As shown in Table 2 the most important country in regard to ferry traffic of the Adriatic-Ionian region was Croatia with almost half of the total passenger movements (7,874,264), despite the fact that it experienced only a 0.7% increase in the last year. Aside from Croatia, the only country that recorded a growth in the number of passengers was Greece (+5.3%).
These two countries have one important characteristic in common; they have a large number of island nearby, which makes for the right conditions for services. In the rest of the countries analyzed, the number of passengers in 2013 decreased. The exception was Slovenia, where the situation remained the same as in 2012, at a near negligible 156 calls per year.

Table 2
Non-cruise traffic by Country, Absolute values and Shares percentage, 2013

Ports	**2013**		**Share on total (%)**		**2012**		**Variation on 2012 (%)**	
Country	Pax. mov.	Calls	Pax. mov.	Calls	Pax. mov.	Calls	Pax. mov.	Calls
Croatia	7,874,264	43,961	46.4	54.2	7,822,238	43,252	0.7	1.6
Greece	4,798,663	27,984	28.3	34.4	4,556,500	28,688	5.3	-2.8
Italy	3,223,948	7,539	19.0	9.3	3,566,808	8,057	-9.6	-6.4
Albania	1,009,186	1,632	6.0	2	1,101,025	1,78	-8	-8
Montenegro	43,097	n.a	0.2	n.a.	53,259	n.a.	-19	n.a.
Slovenia	10,494	156	0.1	0.2	10,494	156	stable	stable
Bosnia-Herzegovina	0	0	0.0	0.0	0	0	0.0	0.0
Total 2013	16,959,652	81,182	100	100	17,110,324	81,935	-0.9	-0.9

Source: Adriatic Sea Tourism Report 2014

The number of ship calls decreased in total by 0.9% in 2013. The ports in almost all countries recorded fewer incoming ships than in 2012, with the exception of Croatia, whose number increased by 1.6% to reach 43,961 calls and, of course, Slovenia.
Figure 6 presents traffic shares regarding passenger movements and ship calls of ten major ferry ports in the Adriatic. The port of Split ranked first in 2013 with a 23.7% share, followed by Igoumenitsa and Zadar with 14.7% and 14.2% respectively. Those three ports accounted for more than 50% of all passenger movements in the Adriatic-Ionian region in 2013. The situation in the number of ship calls was different. The port with the largest share of ferry calls was Zadar (20.9%), followed by Corfu (18.7%), which in passenger movements reached only fourth place. The ports of Split and Igoumenitsa ranked third and fourth with 18.3% and 13.3% respectively. This means that the ports of Split and Igoumenitsa have been accepting larger ferry ships than the ports of Zadar and Corfu.

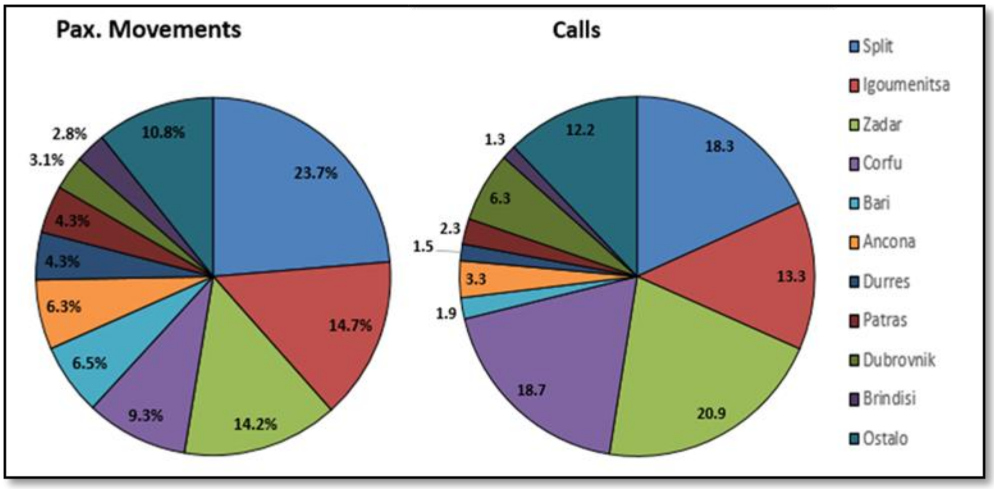


Fig. 6.
Traffic Share of the First 10 Ferry Destinations Among Adriatic Ports (2013)
Source: Adopted from the Adriatic Sea Tourism Report 2014

Further analysis of the ferry traffic in the Adriatic region includes ten ferry ports that were part of the EA SEA-WAY project.

3.1. Analysis of the selected ferry ports in the Adriatic-Ionian region

The study conducted within the EA SEA-WAY project included: the Albanian ports of Vlora, Saranda and Durres, the Greek port of Igoumenitsa, the Italian ports, Ancona, Bari, and Ravenna, the Croatian port of Dubrovnik, the Montenegrin port of Bar and the Slovenian port of Piran.
Among the analysed ports, Bari was the most successful in 2013 with 1,095,810 passengers, while the second and third place belonged to Ancona and Igoumenitsa with 1,064,562 and 900,975 passengers, respectively. By far, the least traffic was accounted for in Ravenna (4,996) (EA SEA WAY project data).

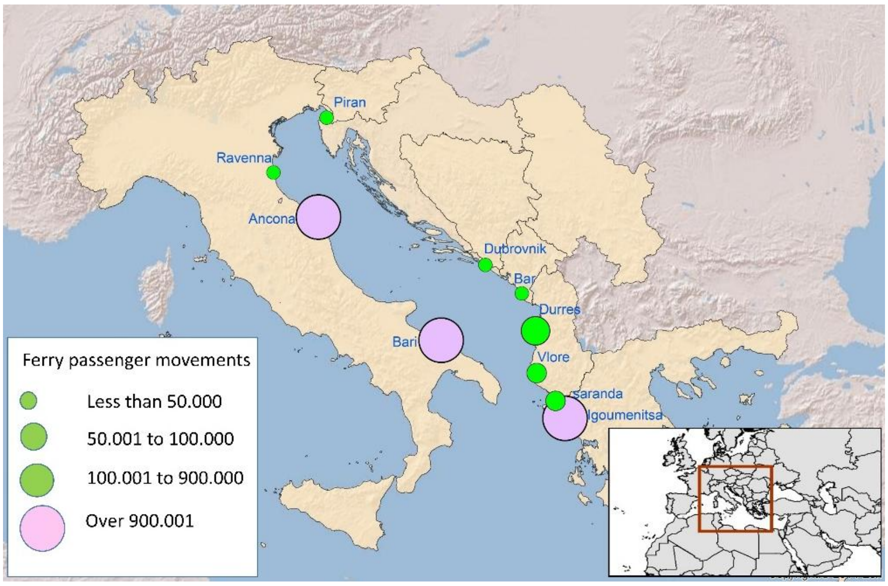


Fig. 7.
Ferry Passenger Movements, Adriatic-Ionian Region, 2013
Source: adopted from EA SEA WAY project data

Compared to 2012, the largest relative growth (17.7%) was recorded in the port of Saranda, followed by Igoumenitsa with 5.8%. Ancona traffic remained almost the same with a mere 0.2% growth. The largest drop in traffic was recorded in Bari at 21%, followed by Bar with an 18% drop, and Vlora with a 17% drop (EA SEA-WAY project data).
The new port of Igoumenitsa is one of the most important ports of the European Union as a category A port, which includes all ports of international importance. It is one of the biggest Ro-Ro ports of international transport in Greece and the eastern Mediterranean. The Port of Igoumenitsa is connected by ferry services to several ports in Italy, namely: Ancona, Bari, Brindisi, Ravenna, Trieste and Venice (Figure 8). The second largest, the port of Bari, is connected to some of the most important Adriatic ferry ports, such as Dubrovnik, Bar, Durrës, Corfu, Igoumenitsa, Patras and Sami. Ancona represents one of the busiest Adriatic ferry ports and is well connected by its port to many other locations. Destinations available from the port of Ancona include Split (with calls at Vis and Hvar), Zadar, Dubrovnik, Bar, Durres, Patras and Igoumenitsa (EA SEA WAY project data).

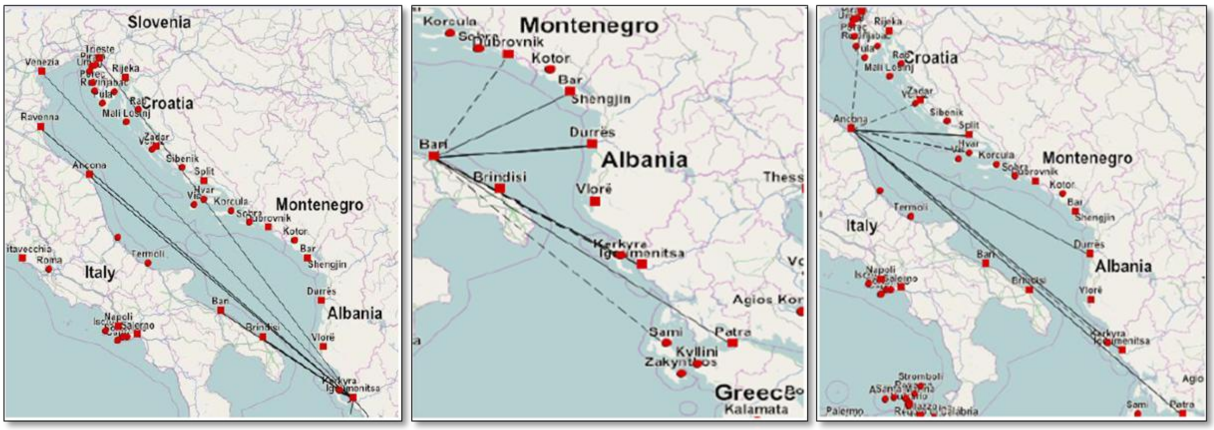


Fig. 8.
Ferry lines from the port of Igoumenitsa, Bari and Ancona
Source: (Ferry Lines, 2014)

The establishments of Ro-Pax ferry lines requires both ports to have adequate terminal capacities, including large parking areas, and terminal services offered to allow the pre-boarding and boarding procedures to be as fluid as possible and the stays of passengers within the port zones to be as pleasant as possible. In addition, the establishment of Ro-Pax ferry lines demands good hinterland connections to extend the catchment area of the service and in this way ensure sufficient demand.
In this segment, ports cannot expect significant progress in the future without good hinterland infrastructure. At this point, road transport is of the utmost importance for the functioning of ferry traffic flows in the Adriatic-Ionian region. Expressed flexibility and ability to quickly respond to modern transport demands have enabled the largest share of road transport at the level of the whole transport market. Although the majority of the Adriatic-Ionian ports are directly connected with railways and this represents a great opportunity for the seaports' competitiveness, the use of rail

transport by passengers is generally limited in the Adriatic-Ionian area, in particular with reference to long distance connections. Such a situation is in ever growing contradiction with the goals of EU integration and environmental sustainability. Apart from current limitations of transport demand, the main reasons for this situation are connected with various problems affecting western Balkans railways: limited size, fragmentation, aged infrastructure and rolling stock, and poor operating and financial performance.

3.2. Portfolio analysis of the selected Adriatic-Ionian ferry ports

The competitive position of ports within this study was, once again, determined using the ″port portfolio analysis″ method. The data used in this analysis was also gathered from the EA SEA-WAY project and port web sites. The time span for the observations was from 2010–2013, which may result in findings not being conclusive due to the short period so further observations are in order for the future verification of results.

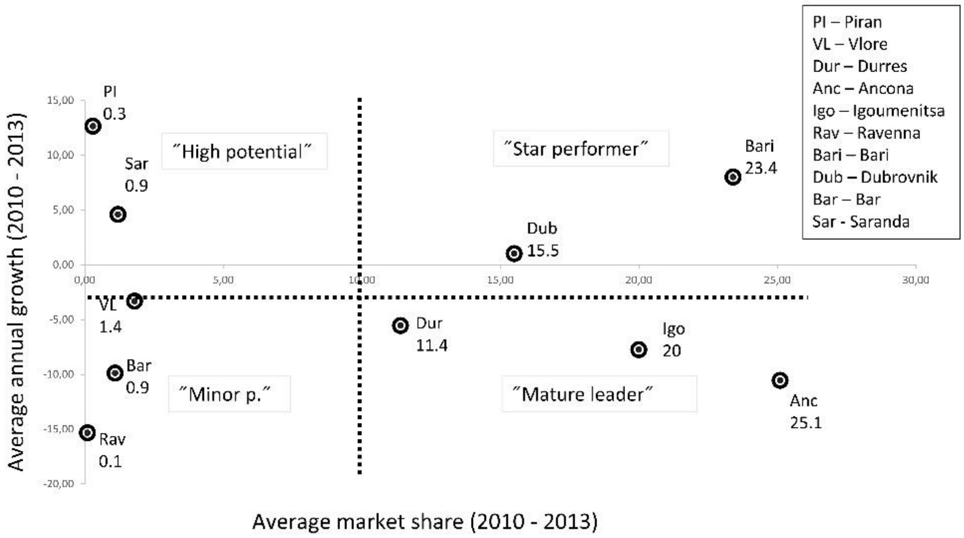


Fig. 9.
Ferry port portfolio analysis
Source: Own calculations

According to Eurostat (EUROSTAT, 2015), ferry passenger traffic in Europe was decreasing in the period from 2008 – 2011 by 11%. In the years 2010/11 the recorded traffic decrease was 4.2%. It was determined that this was the effect of construction of new bridges linking the mainland to islands, which caused many ferry lines to close. Most of the ports within this study continued the downward trend in the following time frame from 2010 onward.

Capturing the biggest and smallest ports of the area proved to be a challenge, since the study was limited to the ports included in the EA SEA-WAY project, but we have managed to show the traffic trends across the ferry traffic market.

The top three ports on our list were Igoumenitsa, Bari and Ancona, together taking a share of almost 70% of all traffic. Including the port of Dubrovnik, these ports take about 85% of all traffic among the ports included in the study. Even though the port of Ancona lost almost 30% of its traffic volume, it still retained over 25% of the market share with about 1.06 million passengers. Due to this drop in 2013, Bari had more traffic than Ancona, with almost 1.1 million passengers and was actually one of the few ports with increased traffic in the observed period.

Among all the ports in the study, only Igoumenitsa recorded significant traffic growth in 2013 (relative increase of +5.8%). Although the port of Piran recorded growth in the 2010 – 2012 timeframe (data for 2013 was not available), we cannot consider it as a high potential port as it is more of a marina than a port, with limited to no further development possibilities. The port of Sarande shows more potential for future growth; however, passenger figures in the observed period have been fluctuating a great deal, so it is impossible to say whether its growth trend will continue. The port of Durres, with over 10% market share, recorded an average 5.5% decrease of traffic from 2011-13 and is following the trend of the entire market, where the ports of Vlore, Bar and Ravenna are no exceptions with -3%, -10% and -15% decreases, respectively.

It will be interesting to see in the coming years whether the predictions of a more than 2% increase for the year 2014 in ferry traffic (Turismo, 2014) will actually be realised.

4. Conclusion

From the analysis, we can conclude that passenger seaborne traffic has a very important role in Europe. Predictions suggest that this sector will continue to grow in terms of ferry connections as well as the cruise sector, despite a certain decrease recorded recently. The European Commission plays a very important role in the promotion of seaborne transport. In recent years, it has significantly invested and supported not only the development of the Motorways of the Sea and Short Sea Shipping, but also ferry services and the development of modern cruising. The latter has now an increasingly important role in the world as well as in Europe. Among European regions, the Mediterranean definitely has a leading position in cruising sector, as it represents the second most important area for cruises in the world. The largest part of the cruise traffic is now taking place among the western Mediterranean ports, while Adriatic ports are gaining ever more importance. In the period from 2010 to 2013 the number of cruise passengers in this area increased by almost 25%. They have therefore high potentials to obtain an even greater share of Mediterranean traffic - as long as they know how to take proper advantage of the opportunities offered to them by the arrivals of an increasing number of ships in recent years. The ratio between the number of passenger movements and received ships shows that certain ports are gradually receiving larger ships that require greater port facilities as well as fast and efficient connections to the key tourist locations in the hinterland.

Through the performed portfolio analysis of the cruising ports in the period 2010 – 2013, we have been able to see that the ports with the largest growth are those, which have the best combination of criteria upon which the cruising companies select their homeports or ports of call. Based on those criteria Venice, Dubrovnik and Bari stand out. Almost all of the selected ports within this study recorded traffic growth in the observed period, indicating further growth in the cruise sector in the future.

The ferry sector lost a number of passengers in recent years (the trends are inconclusive and the drop in number of passengers was especially visible in 2013 in comparison to 2012), nevertheless predictions show that in the future there will be a growing demand for non-cruise passenger traffic in the Adriatic region. This means that as long as ports will want to continue their further development and increase mobility in the region, they will have to improve their inland connections.

However, the analysis in the ferry sector shows an overall decline in traffic in the past few years. Among the ports included in this research, Igoumenitsa, Bari and Ancona stand out in terms of market share, but among the three ports, only Bari recorded traffic growth in the observed time span (2010-2013). All of them recorded high fluctuations in traffic, so the trend is hard to determine. The most stabile traffic figures were recorded by Dubrovnik, which had a constant 1% increase. It will be interesting to see if the demand for non-cruise passenger traffic in the Adriatic region will turn upwards in the upcoming years.

Acknowledgements

This paper is based on the Europe Adriatic SEA-WAY project, which is co-financed by the European Union in the framework of the IPA Adriatic Cross-Border Cooperation Programme 2013-2016.

References

Bagis, O.; Dooms, M. 2014. Turkey's potential on becoming a cruise hub for the East Mediterranean Region: The case of Istanbul, *Research in Transportation Business & Management*, 13: 6-15.

Corres, P.A.J.; Papapchristou, Y. 2013. Competitive and complementary cruise ports: The case of the Eastern Mediterranean. Available from Internet: <http://www.academia.edu>.

Cruise Lines International Association 2015. Cruise Industry Outlook. Available from Internet: <http://www.cruising.org>.

EUROSTAT 2015. Available from Internet: <http://ec.europa.eu/eurostat>.

Lekakou, M.B.; Pallis, A.A.; Vaggelas, G.K. 2009. Which Homeport in Europe: The Cruise industry's selection criteria, *Tourismos: An international multidisciplinary journal of tourism*, 4(4): 215-240.

MedCruise 2014a. Cruise Activities in MedCruise Ports 2014. Available from Internet: <http:// www.medcruise.com>.

MedCruise 2014b. MedCruise 2013/14 yearbook. Available from Internet: <http:// www.medcruise.com>.

Turismo 2014. Adriatic Sea Tourism Report 2014. Available from Internet: < http://www.jura.lt>.

Wergeland, T. 2012. Ferry Passenger Markets. *The Blackwell Companion to Maritime Economics*, Wiley-Blackwell, New York, U.S.A.

ANALYSIS OF THE MAIN OPERATIONS AND THE CHARACTERISTICS OF THE ENVIRONMENTAL MATRIX AT THE ROMANIAN HARBORS IN THE BLACK SEA

Alina Modiga[1], Carmen Gasparotti[2], Liliana Rusu[3], Gabriel Popescu[4]
[1,2,4] *"Dunarea de Jos" Faculty of Naval Architecture, Dunarea de Jos University of Galati, Galati, Romania*
[3] *"Dunarea de Jos" Department of Mechanical Engineering, Dunarea de Jos University of Galati, Galati, Romania*

Abstract: The first objective of the present work is to present an overview of the main operations at the Romanian harbors in the Black Sea. The main harbors considered are Constanta, Navodari and Mangalia. First of all, it has to be noticed that the port activities in the target area were considerably enhanced in the last years. This is due to the considerable increase of the offshore activities in the western side of the Black Sea, as well as to the general enhancement of the human activities in the Romanian coastal environment and to the high dynamics of the economy grows in both nearshore and offshore areas. On the other hand, this implies also the coastal navigation of the river ships that are more exposed in the case of the harshest sea conditions. From this perspective, a second target of the proposed work is to analyze the main features of the environmental matrix in the vicinity of the harbor areas. For his reason, simulations with a wave modelling system, based on the spectral phase average model SWAN (acronym from Simulating Waves Nearshore), have been carried out for an extended time interval covering the 15-year period 1999-2013. The wind field considered for these simulations is that provided by NCEP-CFSR (United States National Centers for Environmental Prediction, Climate Forecast System Reanalysis) with a spatial resolution of 0.312º×0.312º and a temporal resolution of 3 hours. Moreover, in order to increase the accuracy of the wave predictions, some assimilation techniques of the satellite data, based on the Optimal Interpolation method, have been also implemented. Having as a basis this data set, a comprehensive picture of the wind and wave conditions in the vicinity of the main Romanian harbors has been provided.

Keywords: Black Sea, Romanian nearshore, harbor operations, environmental matrix, coastal hazards.

1. Introduction

The transportation has a very important role in every country's economy, since any product can be used only after it arrives, with the help of the transport means from the place of production to the use point. The transportation substantially contributes to attracting, in the economic circle, of the new territories, material and human resources and development of the foreign trade. The material resources are not evenly distributed on the globe, so it is necessary to be transported for long distances between different geographic areas of the world, by air, by rail, by road, inland waterway, by sea or by pipelines. The transportation requires a quarter of global consumption of fuel, one-third of electricity produced, 70% of rubber production, oils, metals and the others, so that it must be done in the most economical way.
Water transportation is used both within a country and also for the trade between countries of the same continent, or on the different continents (Ministry of Transport. Report on Master Plan on short, medium and long term of Romania transport).
The maritime transportation plays a crucial role in achieving of the movement of goods, both in terms of quantity and of the operability. This role is given by aspects such as relatively low cost, compared to the large volume of goods that can be transported, the complex and diverse nature of trade, the increasing of the number of participants in these exchanges.
The main elements underlying the definition of maritime transport are the following: the goods characterized by a large volume and high value, the ships as a means of transport and the ports as transshipment nodes and the facilities operating within them. It can be said that shipping is a particularly complex economic activity, having a national and international character, that must be conducted both after the needs and to ensure the profitability. The main function of maritime transport is to ensure the link between production and consumption and is characterized by two major features: economic efficiency and the profitability, involving the actual transport costs and the costs of the related operations (Rusu et al, 2014). These two features depend on the three elements that underlying of the definition of the shipping: goods, ships and ports.
The ports are the nodal points where large quantities of goods can be dispersed by destination on the various routes and by all means of transport (Ciortan, 2012). This is the reason of the water transport development of a country that should be placed in the context of the worldwide transport development and of the worldwide traffic intensifying of the goods. This is one of the most efficient means of transport, from the economic point of view, benefiting from the existence of the natural waterways. A particular importance for the transport is the commercial speed, which means the average speed of the way, including parking and for this indicator the maritime transport is situated on top of the hierarchy: 460-600 km/day, followed by transport by rail – 28-350km/day, and the inland transport – 150-200km/day (Ciortan, 2015).

2. Ports on the Black Sea

The Black Sea is an intercontinental sea located between southeast Europe and western Asia. Through the system of straits Bosporus- Dardanelles-Marmara Sea it communicates to the Mediterranean Sea and through the Kerch Strait with the Sea of Azov. It is bordered by the Pontic Mountains to the south and by the Caucasus Mountains to the east,

[1] Corresponding author: alina.modiga@ugal.ro

with a wide opening to the northwest. In the Black Sea there are numerous rivers that flow, such as: Danube, Dniester, Bug, Dnieper, Rioni, Kizil-Irmak and therefore its salinity is low (on average 20 to 22 o/00) compared to the planetary ocean. Many of these rivers are navigable, contributing to expanding the Black Sea hinterland.
The area of the Black Sea is about 411,540 km2, the maximum depth being about 2,212 m and the volume is 547,000 km3. Together with the Sea of Azov are bordered by six countries: Bulgaria, Georgia, Romania, Russia, Turkey, and Ukraine, and there are at least 35 harbors including 30 operating merchant seaports in the Black Sea. There are many important cities along the coast such as Batumi, Burgas, Constanța, Giresun, Hopa, Istanbul, Kerch, Mangalia, Năvodari, Novorossiysk, Odessa, Ordu, Poti, Rize, Sinop, Samsun, Sevastopol, Sochi, Sozopol, Sukhumi, Trabzon, Varna, Yalta and Zonguldak (Ports from the Black Sea and Danube). The harbors located in the Black Sea region are shown in Figure 1.

Fig. 1.
The maritime harbors on the Black Sea
Source: (https://commons.wikimedia.org/wiki/User:NormanEinstein)

The Romanian ports on the Black Sea are: Constanta, Midia Navodari and Mangalia. Development of the water transport in Romania was favored by the existence of over 200 km of coastline along the Black Sea and about 1,300 km of inland waterways. The Danube is one of the most important inland waterways in Europe, having a navigable length of 2,588 km from which 1,075 km run through Romania. To the benefits of this navigable potential were constructed 30 port facilities, as part of a transport integrated system. Some of these are of great complexity, integrated into the road, rail and air Romanian transport system. In this way it can be ensured the maritime connections with all the world's oceans, as well as the countries of Central and Western Europe. The Danube hinterland was substantially expanded through the channels Danube-Black Sea and Poarta-Alba-Midia-Navodari, which led to the development of a major traffic of goods, contributing significantly to the Romania's economic development. Thus, in Romania, in 2013 there were transported 317 million tons of goods including 76.4 million tons of goods on waterways (maritime - 44.48 million tons, inland navigation-26.62 million tons and 5.4 million tons via pipelines).

2.1. Issues identified in harbors

Constanta harbor has an outdated infrastructure that is inadequate for operating new flows of goods, including containers. Although it is an important harbor for container traffic, in 2013 have been operated only 661, 000 TEU compared to the peak year 2007 for the container traffic, when there were operated 1.41 million TEU. The current economic conditions, particularly the low fares paid for the container transport, have affected the shipping lines, which remained increasingly less to service the harbor and the platforms of common services arrive with containers for multiple shipping lines. It also requires the improving of the harbor connectivity.
The problems identified in the Constanta harbor are: old or undeveloped infrastructure, poor connectivity, the inability to operate new flows, capacity deficit (Raileanu et al, 2015).

2.2. Critical conditions for navigation

Shipping is a complex activity both by volume and nature of goods in traffic, but rather by specific operating conditions, seas and oceans imposing special measures for the safety of the ship.
In maritime transport people interact with technology, the environment and organizational factors, each of which having a determining role in the safety of the ship at sea (Gasparotti et al, 2014).
It admits that the production of accidents at sea is inevitable. There is a set of causes that lead to an accident. They consist of in high density traffic, unfavorable hydrometeorological conditions (storms, waves, rain, frost), navigation obstacles, conditions of the sea (sea depth and the topography of the seabed), reduced visibility, human errors, defects of the ship, fall out of gas in the tanks. These may individually or in combination lead to marine accidents (Gasparotti and Rusu, 2012).

It is widely accepted that marine accidents are not caused by a single cause, but a multitude of causes, including human factor, organizational and technological factors (Onea and Rusu, 2014a, b). Statistics show that most accidents occurred due to heavy hydro-meteorological conditions and human error. The most dramatic situations occur when these two factors are met, leading to loss of life, property damage and environmental pollution (Rusu and Guedes Soares, 2011).

In the Black Sea, the most accidents occurred during winter (November to March), when there are the worst hydro-meteorological conditions, strong wind, fog, heavy snow, low temperatures that produce ice on the deck and the superstructure of the ship affecting the buoyancy of the ship (Gasparotti and Rusu, 2014). In winter, the frequency of wind with high speeds is larger than the rest of the year. The winds with speeds of 11 and 15 m/s reach in winter 12-25% of all those present, and winds with speeds of 15 m/s reach to 10%, compared to the annual average of 3-5% (the characteristics of hydro-meteorological area of the Danube). Often the strong winds are accompanied by heavy precipitation, snowstorm and low visibility situations that can have lasting 13 to 45 days, that are accompanied by strong frosts increase the likelihood of marine disasters (Ivan et al, 2012).

3. Romanian ports on the Black Sea

Constanta Harbor The Constanța harbor is located on the western coast of the Black Sea, at 332 km from he Bosporus Strait and 157 km, from the Sulina Branch. The harbor has a favorable geographical position being connected with two Pan-European transport corridors: Corridor VII – Danube (inland waterway) and Corridor IV (railway). Together with the two satellite ports, Mangalia and Midia are part of the Romanian maritime port system. The Constanta harbor has a handling capacity of 100,000,000 tones per year and 156 berths, of which 140 berths are operational. It is divided into:
The *maritime harbor* has an annual operating capacity of 100 million tons and is serviced by 140 functional berths allowing access the ships with a capacity of 220,000 dwt.
The River port allows the access to any type of river ship having an annual handling capacity of 10 million tons. This port handles about 200 daily river ships.
The *tourist harbor* is a major milestone for passenger ships sailing along the Black Sea. Due to the total quay length of 29.8 kilometers with depths between 8 and 19 meters the Constanta harbor has become one of the most important European and international ports, allowing the accommodation of tankers with a capacity of 165,000 tonnes deadweight (dwt) and bulk carriers of 220,000 dwt. Constanța harbor is both a maritime and a river port, in which more than 200 river vessels/day are in the port for cargo loading or unloading. The Constanta harbor is connected with the Danube River through the Danube–Black Sea Canal, which represents one of the main strengths of Constanța Port. The cargo quantities are carried by river, between Constanta and Central and Eastern European countries, such as: Bulgaria, Serbia, Hungary, Austria, Slovakia and Germany.
The river traffic for the Constanța Port has had a share of 23.3% of the total traffic in 2005. The traffic started growing after 2003 and reached a record 61,838,000 tonnes and in 2008 there was the second largest cargo traffic in the history of the port. The most important terminals which are operational since 2004 there were: container terminal, passenger terminal, barge terminal and the oil terminal which has seven operational jetties that allow berthage for the ships up to 165,000 dwt capacity (National Institute of Statistics) (www.portofconstantza.com). In 2014 the Constanța harbor there were handled a total traffic of 55,641,910 tonnes of cargo and 668,293 twenty-foot equivalent units (TEU).
Mangalia Harbor Mangalia is a harbor for yachts and small boats up to 18 m long located on the Black Sea coast very close to the southern border with Bulgaria, at 38 km south of Constanta. It is the most modern tourist harbor in Romania, that covers 142.19 ha of which 27.47 ha is land and 114.72 ha is water. The harbor has the breakwaters with a total length of 2.74 km and 4 berths from which 2 are operational berths with a total length of 540 m. The maximum depth in the harbor is 9 m.
Midia Harbor The Port of Midia is located on the Black Sea coastline at 25.0 km north of Constanța, having breakwaters with a total length of 6.7 km. It covers 834 ha of which 234 ha is land and 600 ha is water and it has 14 berths from which 11 operational berths and three berths belong to Constanța Shipyard, with a total length of 2.24 km. The harbor depths are till 9 m at crude oil discharging berths 1–4, allowing access to tankers having a 8.5 m maximum draught and 20,000 dwt (www.portofconstantza.com).

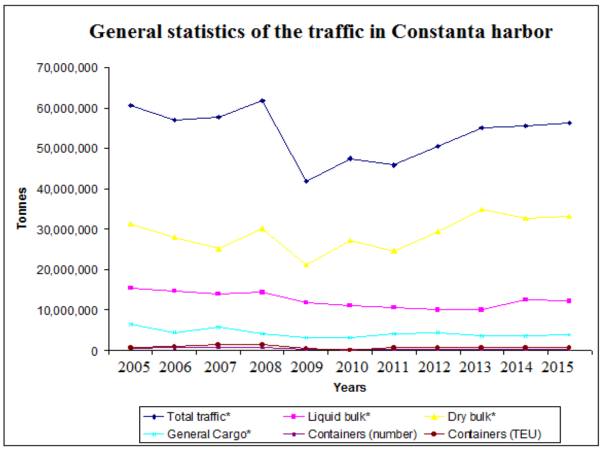


Fig. 2.
General statistics of the traffic in Constanta harbor
Source: (www.portofconstantza.com.)

3.1. The main port operations

An accelerated growth of the world maritime traffic as a result of increasing the demand for raw materials and industrial products, has led to the diversification and specialization of the maritime transport and the increase of the ship's tonnage. Assuring of a wide range of services is essential to any port, and the satisfying of these requirements is an important factor for asserting on a "market harbors" that already exist worldwide. To become a modern port, the Constanta port was adapted to the needs of the transformation process of the international transport network providing a variety of services to everyone with who comes in contact: goods, ship, crew, port operators etc. (Vlasceanuet et al, 2015).
The seaports on the Black Sea ensure the optimal conditions for carrying out of all the activities of ships that coming into the port, such as: input and output, harboring when there are extreme weather conditions, the supplying and bunkering, the maintenance and repair and mainly the carrying out of all the port operations related to the exploitation during the shipping (Omer et al, 2015).
The main port public services that are provided, are: the pilotage of the ships at the entering and leaving the ports, as well as the handling from one berth to another; binding-unbinding the ships; the towing of the ships; the taking of the waste, sewage and garbage from ships; fire extinction from the ships and on the floating facilities located in ports; decontamination of the port waters and taking garbage from the economic agents operating in the ports. In the category of other services provided, are: loading/unloading, storage, handling, mooring, labeling, palletizing, expeditions national and international control services, goods, the rescue of the ships and the human life, repair of ships in the shipyards or outside, the international service of shipping and cargo etc. (www.portofconstantza.com).

3.2. Dynamics of the cargo traffic in the main harbors

The total goods traffic registered in the Romanian maritime harbors Constanța, Media and Mangalia was 32.71 million tons in the first seven months of 2016 in comparison with 33.41 million tones corresponding to the same period of 2015. On the other hand, the maritime traffic was of 25.64 million tons against 25.36 million tons at 31 July 2015, and the river traffic was 7.07 million tones, in comparison with 8.04 million tons at 31 July 2015.
In terms of transit goods through ports, the first place holds the cereals, followed by miscellaneous items, solid fuels and mineral oil products. The iron ore is ranked on the fifth place and are followed by non-ferrous ores and waste, chemicals and metal products and vegetables, fruits and cellulose are on the last places among the quantities of goods transited through Romanian ports.
The cargo traffic in the Constanta harbor is shown in Figure 3. The maritime traffic has had an ascending trend in the period 2009-2015 when it has increased in 2015 by 27.7% compared to 2009. The general statistics, calls of seagoing ships by capacity in the Constanta, Mangalia and Midia harbors are shown in Figure 4. In figure 4, it can be observed that calls of seagoing ships in all three harbors are the highest for the ship capacity until 5000 dtw.

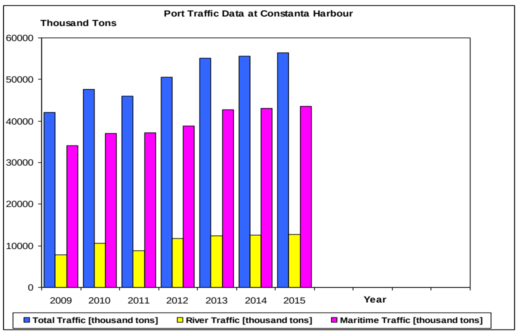


Fig. 3.
Port traffic data in Constanta harbor
Source: (www.portofconstantza.com.)

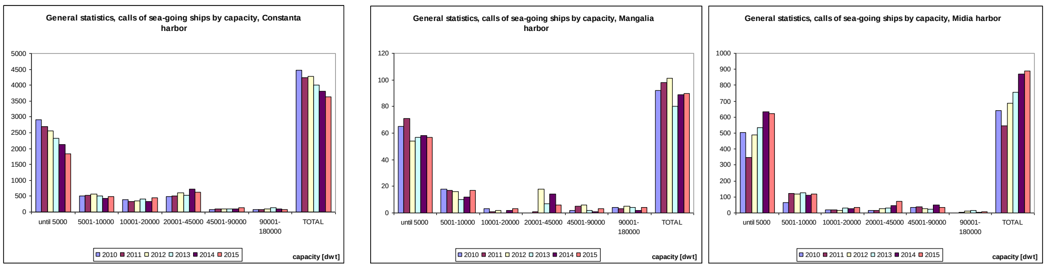


Fig. 4.
General statistics, calls of seagoing ships by capacity in Constanta, Mangalia and Sulina harbors, respectively.
Source: (www.portofconstantza.com)

4. Characteristics of the environmental matrix close to the harbor areas

In order to analyze the wave conditions in the vicinity of the main Romanian harbors a SWAN based wave modeling system was implemented and extensively tested in the Black Sea (see for example Rusu, 2010 and Rusu and Butunoiu, 2015). Moreover, this system was used to assess the extreme storm conditions along the Black Sea with the emphasis on the western side of the basin (Rusu et al., 2013). Further on, some data assimilation techniques have been also implemented in order to increase the accuracy of the model results.
For the present work simulations with this wave prediction system have been performed for the 15-year time interval 1999-2013 and, on this basis, an analysis of the most representative wave parameter (significant wave height - Hs) has been carried out. Thus, Fig. 5 illustrates the Hs histograms close to the main Romanian harbors. It can be noticed that close to the Constanta harbor, although most of the occurrences are in the range 0-1 meters, there exist however significant wave heights greater than 6 meters.

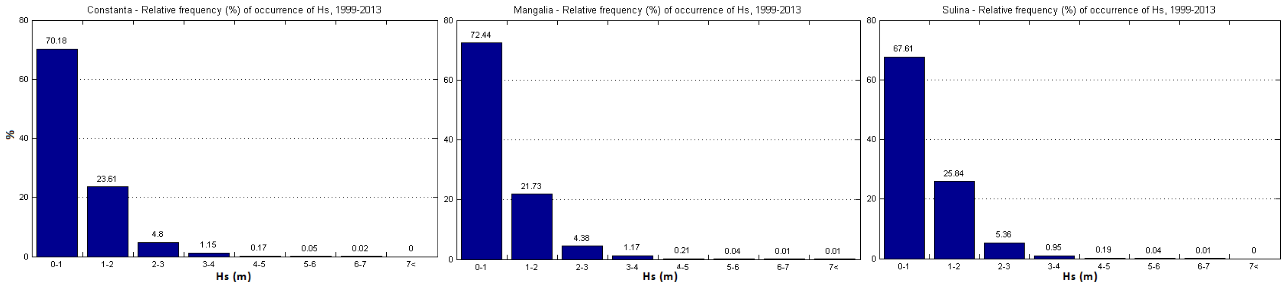


Fig. 5.
HS histograms close to Constanta (left panel), Mangalia (middle panel) and Sulina (right panel) harbors, respectively

The corresponding wave roses are presented in Fig. 6. As it can be seen, most of the waves are coming from North-Northeast, although the wave directions from South-Southeast are also representative. We can notice that close to Mangalia harbor there are waves with significant wave heights greater than seven meters, in a higher percentage than close to the harbors Constanta and Sulina.

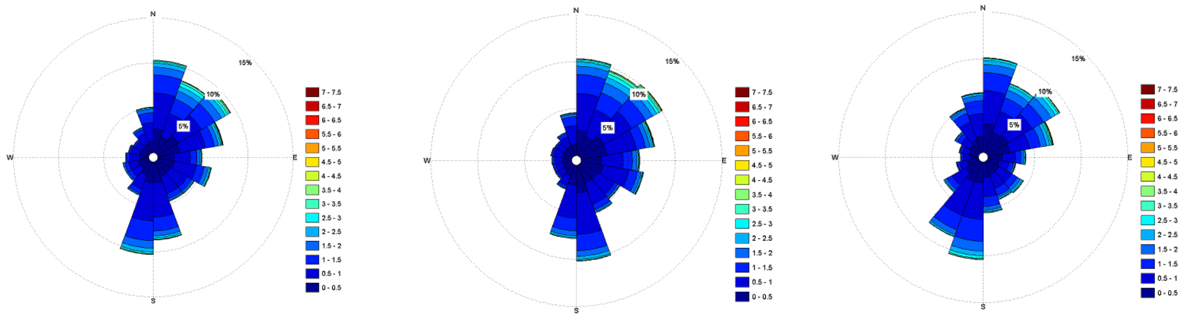


Fig. 6.
HS wave roses close to Constanta (left panel), Mangalia (middle panel) and Sulina (right panel) harbors, respectively

Looking at figures 5 and 6, it can be highlighted that the wave conditions close to the Romanian harbors at the Black Sea are very often quite strong and that is why an adequate knowledge of the main characteristics of the environmental matrix in the vicinity of the harbors (including also the extreme conditions that might be expected) represents an issue of crucial importance for the safety of the harbor operations.

5. Conclusions

The importance of the maritime transportation has determined the development of a broad international cooperation to ensure: avoiding the accidents and the organization of the assistance and the maritime rescue, the safety of life and ships at sea, the unification of legislation and methodology in the maritime transportation, the pollution prevention of the environment in general and of the marine environment in particularly, the protection of the ship-owners and cargo owners, the assurance of the goods, ships and people. Also, it is aimed to establish for the maritime trade, an appropriate legal and economic framework, equitable, sustainable and workable, amid international cooperation, guaranteeing functionality, equal rights and obligations of the partners. The first quarter of 2016 ended with a decrease of 7.8% of total freight traffic compared with the same period in 2015. The three ports of Constanta, Midia and Mangalia, were held together 12,907,895 tons, with 1,093,423 tons less compared to the first quarter of last year. At the negative result have contributed, mainly, the grain flows decrease by 35% and solid mineral fuels, by 27%.
Constanta port has performed 85.07% of cargo flows, while the Midia port only 14.50% and Mangalia port - 0.43%.

In terms of maritime traffic, this decreased by 4.04%, registering 10.22 million tons, and the river traffic was down by 19.76, reaching 2.68 million tons. In 2016 Constanta port has handled 10.981.333 tons of goods, down with 11.32%, or 1,401,965 tons compared to 2015. The grains and oilseeds continue to hold the largest share in total flows of goods, but this was reduced from 44.53% in 2015 at 32.40% in the first quarter of 2016. The container traffic in the port of Constanta has totaled 1,739,857 tonnes or 174 235 TEU, up by 9.18% and 10.43%, respectively, but remains well below the existing operating capacity.
The Midia harbor goes through a period of growth, recording a traffic of 1,872,242 tons, with 19.91% higher than the same period last year. The positive evolution was due to the quantities of oil and petroleum products larger with 31.46% and 4.60% respectively.
Mangalia harbor has performed only 54 320 tonnes, 4.09% below the level achieved in the first quarter of 2015.

References

Butunoiu D.; Rusu E. 2014. Wave modeling with data assimilations to support the navigations in the Black Sea close to the Romanian ports. In *Proceedings of the Second International Conference on Traffic and Transport Engineering* (ICTTE), 180-187.

Ciortan R., 2015. Aspecte privind infrastructura pentru navigatie in Romania, Buletinul AGIR nr. 3/2015 iulie-septembrie. Available from internet: <http://www.agir.ro/buletine/2392.pdf>.

Ciortan, R. 2012. Porturi si amenajari portuare, Ed. AGIR, Bucuresti, Compania Nationala Administratia Porturilor Maritime SA Constanta. Available from internet: <http://www.portofconstantza.com/apmc>.

Gasparotti, C.; Rusu, E. 2012. Methods for the risk assessment in maritime transportation in the Black Sea basin. Protection and Sustainable Management of the Black Sea Ecosystem, *Journal of Environmental Protection and Ecology*, 13(3A): 1751-1759.

Gasparotti, C.; Domnisoru, L.; Rusu, E. 2014. Scenarios for the navigation routes in the Black Sea considering the seakeeping safety criteria. In *Proceedings of the 14th International Multidisciplinary Scientific GeoConference (SGEM2014)*, 2: 677-684.

Gasparotti, C.; Rusu, L. 2014. Prediction of the dynamic responses for two containerships operating in the Black Sea, *Journal of Naval Architecture and Marine Engineering*, 11(1): 55-68.

Ivan, A.; Gasparotti, C.; Rusu E. 2012. Influence of the interactions between waves and currents on the navigation at the entrance of the Danube Delta, *Journal of Environmental Protection and Ecology*, 13(3A): 1673-1682.

Ministry of Transport. Report on Master Plan on short, medium and long term of Romania transport. Available from Internet: <http://mt.ro/web14/documente/master_plan/partea%20II%20master%20plan%20final.pdf>.

National Institute of Statistics (INSSE). Available from internet: <http://www.insse.ro/cms/ro/content/arhiva-publicatiilor-statistice-2007-2015>.

Omer, I.; Mateescu, R.; Rusu, L.; Niculescu, D.; Vlasceanu, E. 2015. Coastal works extensions on the Romanian touristic littoral, its ecological impacts on the nearshore bathing areas, *Journal of Environmental Protection and Ecology*, 16(2): 424-433.

Onea, F.; Rusu, E. 2014a. Evaluations of the Wind Energy in the North-West of the Black Sea, *International Journal of Green Energy*, 11(5): 465-487.

Onea, F.; Rusu, E. 2014b. Wind Energy Assessments Along the Black Sea Basin, *Meteorological Applications*, 21(2): 316-329.

Ports from the Black Sea and Danube. Available from internet: <http://www.practicanavala.ro/POSDRU/161/2.1/G/140706/>.

Raileanu, A.; Rusu, L.; Rusu, E. 2015. *Wave modeling with data assimilation in the Romanian nearshore*. Towards Green Marine Technology and Transport – Guedes Soares Dejhalla&Pavletic (Eds), CRC Press, Taylor&Francis Group, London, UK.

Regulament portuar al porturilor situate pe Canalul Dunarea-Marea Neagra si Canalul Poartea Alba- Midia Navodari (in Romanian)

Rusu, E.; Guedes Soares, C. 2011. Wave modeling at the entrance of ports, *Ocean Engineering*, 38(17-18): 2089-2109.

Rusu, E. 2010. Modeling of wave-current interactions at the Danube’s mouths, *Journal of Marine Science and Technology*, 15(2): 143-159.

Rusu, L.; Butunoiu, D.; Rusu, E. 2014. Analysis of the extreme storm events in the Black Sea considering the results of a ten-year wave hindcast, *Journal of Environmental Protection and Ecology*, 15(2): 445-454.

Rusu, L.; Butunoiu, D. 2015. Numerical modeling of the wave propagation close to the Sacalin island in the Black Sea, *Journal of Marine Science and Technology*-Taiwan, 23(5): 669-677.

Rusu, L.; Bernardino, M.; Guedes Soares, C. 2014. Wind and wave modeling in the Black Sea, *Journal of Operational Oceanography*, 7(1): 5-20.

Vlasceanu, E.; Omer, I.; Niculescu, D.; Rusu, E.; Ivan, A. 2015. Modelling aspects of the hydro-geomorphological process and their impact on the evolution of the Romanian coastal eco-system on the Black Sea, in the context of the new climate change. In In *Proceedings of the 15th International Multidisciplinary Scientific GeoConference* (SGEM2015), 2: 667-674.

ANALYSIS OF STABILITY OF PONTOON TYPE MARINE VEHICLE IN THE BAY OF VLORA

Kristofor Lapa[1], Blenard Xhaferaj[2]
[1,2] University "Ismail Qemali", Skele, Vlore, Albania

Abstract: Navigation safety is of particular importance especially on pontoon type marine vehicle that operate in specific areas. Pontoon is designed and built in the Pashaliman shipyard in Vlore in southwestern Albania. Its purpose is to supply the Albanian local fish farms with nutrients and it is designed to navigate within the bay of Vlora with a depth that goes up to 50 m. In order to be classified and get the navigation permission by the Albanian Shipping Register, the ship owner is asked to carry out the necessary technical documentation. Hydrostatic calculations and the verification of Stability Criteria are done with the help of Maxsurf package. Different situations are presented and analyzed in this paper by generalizing the respective conclusions.

Keywords: the bay of Vlora, MaxSurf software, ship stability, pontoon, marine vehicle.

1. Introduction

Fish farming sector is growing rapidly in Albania, mainly in the Gulf of Vlora. Small marine vessels are on increased demand in support of these farms. Pontoon vessel was built in the unique shipyard of Pashaliman and serves for communication with the farms for supplying food and obtaining fish from them. For this marine vehicle, after it was built, in order to guarantee navigation safety, it was requested from his owner the necessary documentation by the Maritime Register of Albania. With the help of technical drawings of the vehicle under construction and some other measurements made in pontoon after its construction, the modeling of pontoon in Maxsurf program was conducted and the verification of criteria was made for a secure stability in navigation.

2. 3D CAD modeling of the floating Pontoon hull

3D CAD modeling of the ship hull was made, after the shipyard made available for us the preliminary technical drawings of the initial project of the vehicle. The first step in building CAD model of this hull was to review the form of the hull. According to the preliminary design of the ship, it is a two-body vehicle with a distance of 0.5 m between them. Each of the semi-bodies is characterized by the fact that in a length of the hull of 12.25 m the transverse sections are unchanged. The sections in this length are transversal sections of the blade and an arising angle equal to 20^0. The bow body extends in a length of 1.45 m.
3D-CAD model was designed directly with the help of Maxsurf program, without the need to prebuild it in Prefit Program. The surface of the hull was designed by building first the surface of the demi-hull and then by duplicating this surface in order to take the final model of the pontoon hull. In the end all the surfaces were checked in order to respect the geometric boundary conditions.
The building of the 3D model of the ship hull was based on real measurements on preliminary technical drawing. Below are presented the main steps of CAD modeling process (Xhaferaj, 2008):

1. The necessary measurements in the preliminary technical drawing of the hull.
2. Modeling of each demi-hull surfaces by modeling individually each region of the hull (bow, stern, central body).
3. Union of individual surfaces modeled before taking the preliminary demi-hull form.
4. Checks of initial conditions of the designed demi-hull with geometry of the ship.
5. Smoothing of the surface of the CAD model of the demi hull.
6. Duplication of the demi hull in order to have the final form of the ship.
7. The drawing of the CAD model of the modeled hull is carried out.

[1] Corresponding author: kristoforlapa@gmail.com

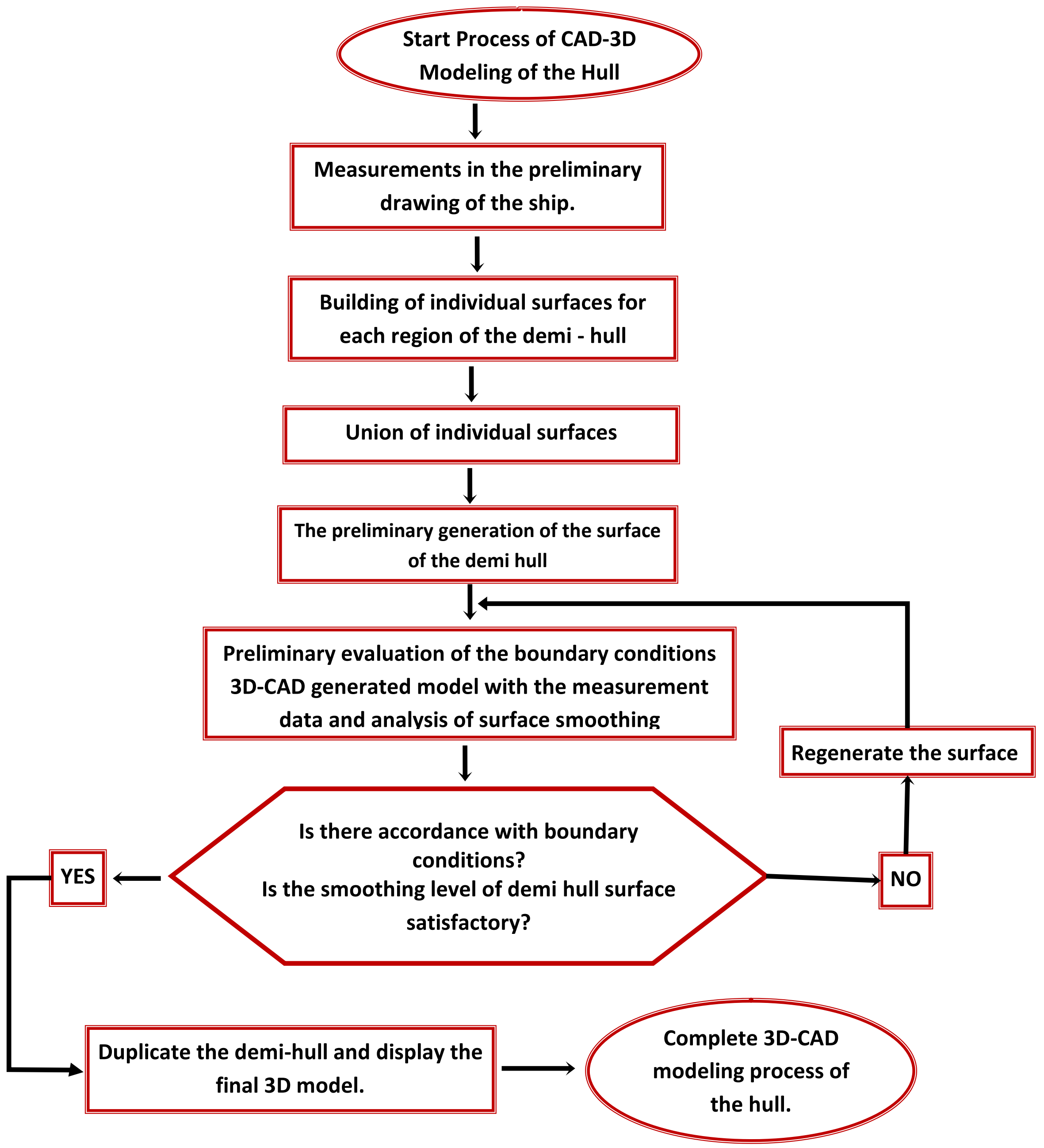


Fig. 1.
General flow chart of the process of rebuilding the hull
Source: Designed by the authors

Table 1
Main dimensions of Almarina pontoon

Length Overall	LOA = 14.60 m	Crew Number	3
		Main Engine	2x300 HP SUZUKI
Breadth Overall	BOA = 5.50 m	Construction Material	Steel
Depth	D = 1.45 m	Year of Construction	2016
Draft	T = 0.85 m	Place of Construction	Pashaliman Shipyard, Vlore

Source: Pontoon data and real measurements

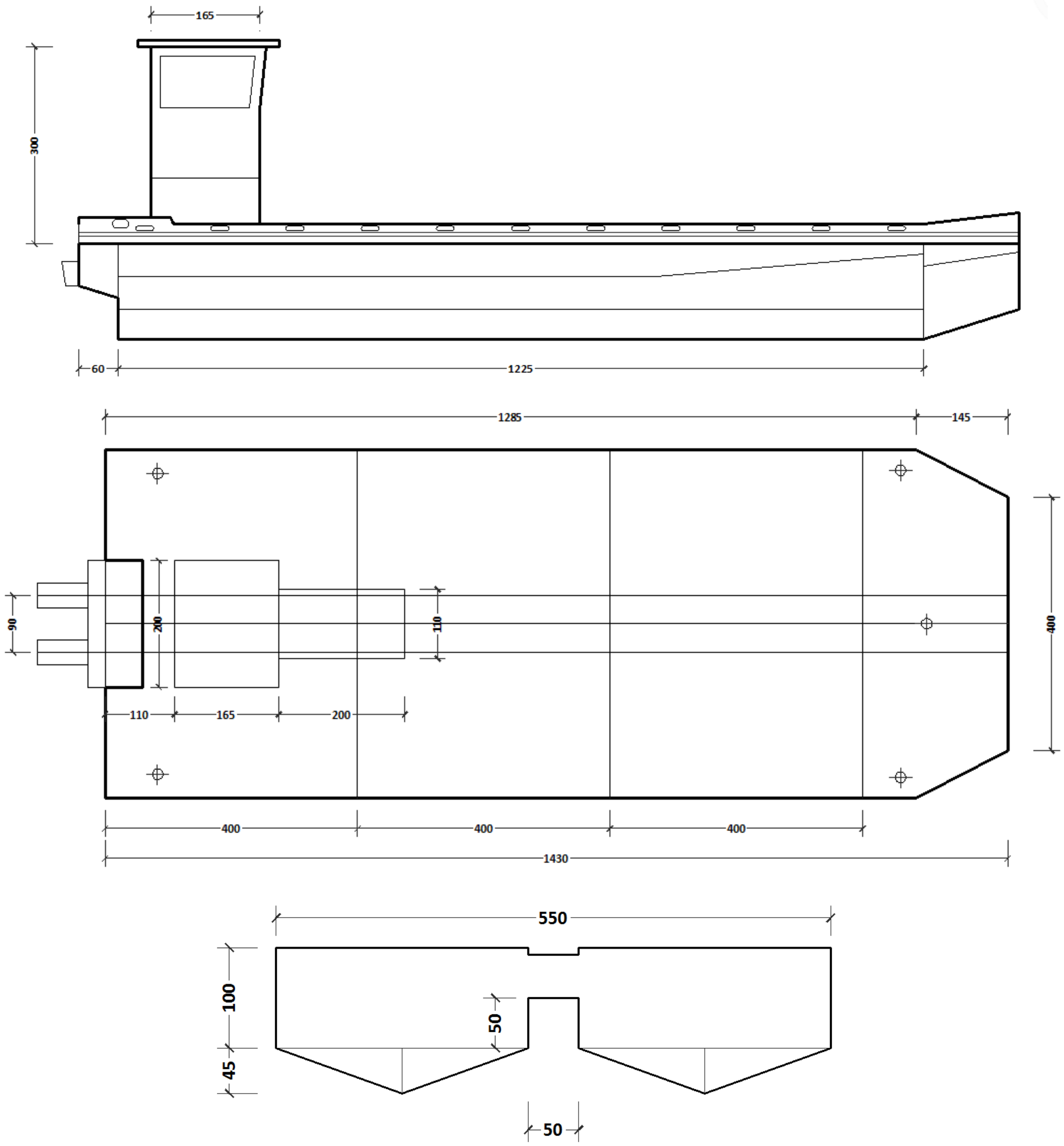


Fig. 2.
General arrangement of the Almarina pontoon
Source: Designed by ourselves in AutoCAD program

Control points of the modeling hull surface in Maxsurf program have some limitations and their movement is needed to achieve a surface model without irregularities and to continue improving until reaching the optimal surface.
The obtained surface shown, in the following figures, seems to be a very good surface in respect of predetermined requirements. With the data obtained from the project and verification of measurements directly on the pontoon under construction, because of some deviations and modifications done during the construction process, by using the Maxsurf program, after a number of iterations, we obtained the final version of pontoon as shown in the following figures (Bentley, 2009), (Xhaferaj, 2010).

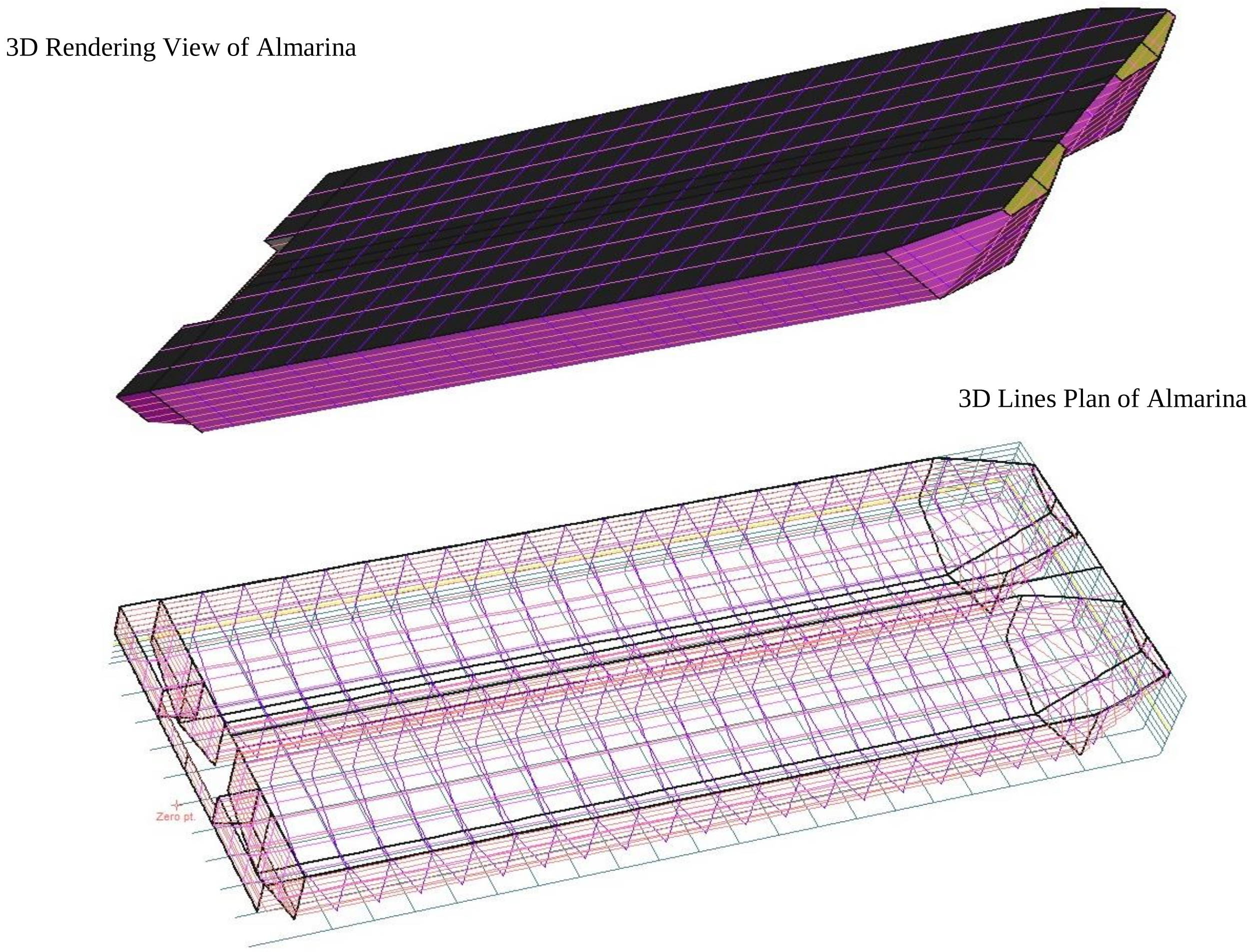


Fig. 3.
The final form of the floating pontoon model after the consecutive iterations
Source: Designed by ourselves in Maxsurf program

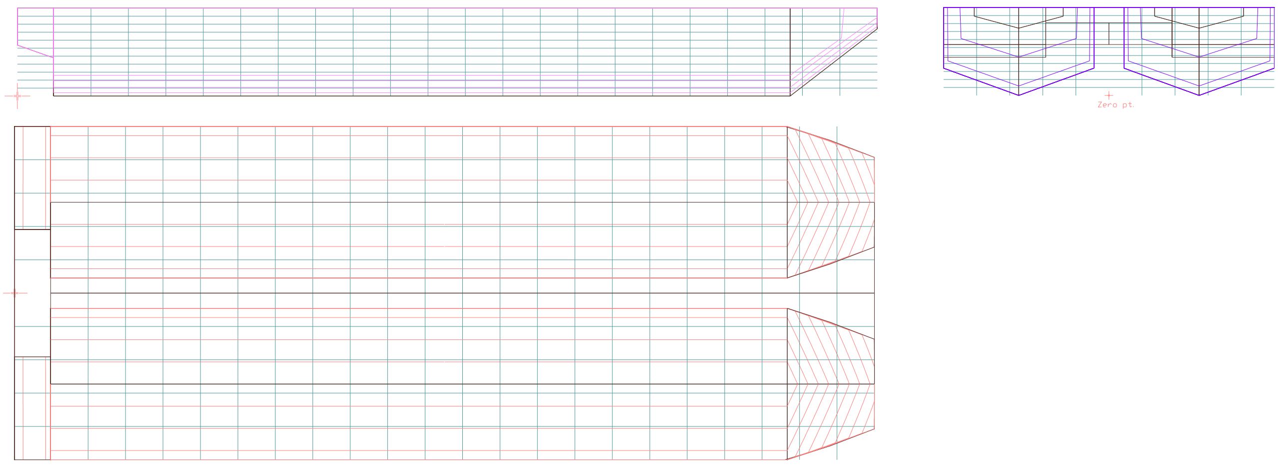


Fig. 4.
Line Plan of ALMARINA
Source: Designed by ourselves in Maxsurf program

3. Evaluation of static and dynamic stability and verification of general and meteorological criteria of the pontoon type marine vehicle taken in the study

After receiving the acceptable version of 3D CAD form of Almarina pontoon hull, a series of calculations of hydrostatic and stability nature and the verification according the IMO regulations were carried out. Out of the comparison of these values relevant suggestions to the pontoon under construction were made, to be considered during its final construction and lunching to water.

3.1. Hydrostatic DATA

Hydrostatic data are calculated with the help of Maxsurf and Hydromax Software (Bentley, 2009), (Lapa, 2015), (Lapa, 2016). Here we present the data of the vessel with full load, that correspond waterline DWL=0.85m.

Table 1
Hydrostatic DATA of "ALMARINA" pontoon

Draft Amidships (m)	**0.800**	**0.900**			
Displacement (t)	37.37	44.25	Max Sect. area coeff. (Cm)	0.719	0.750
Draft at FP (m)	0.800	0.900	Waterpl. Area coeff. (Cwp)	0.877	0.874
Draft at AP (m)	0.800	0.900	LCB from zero pt. (+ve fwd) m	6.899	6.902
Draft at LCF (m)	0.800	0.900	LCF from zero pt. (+ve fwd) m	6.922	6.944
WL Length (m)	13.781	14.026	KB (m)	0.501	0.556
Beam max extents on WL (m)	5.500	5.500	BMt (m)	5.083	4.362
Wetted Area (m^2)	90.341	97.268	KMt (m)	5.584	4.917
Waterpl. Area (m^2)	66.446	67.406	KML (m)	27.443	24.347
Prismatic coefficient (Cp)	0.920	0.912	Immersion (TPc) (tonne/cm)	0.681	0.691
Block coefficient (Cb)	0.601	0.621	MTc tonne (m)	0.781	0.818

Source: Results taken by ourselves in Maxsurf and Hydromax program

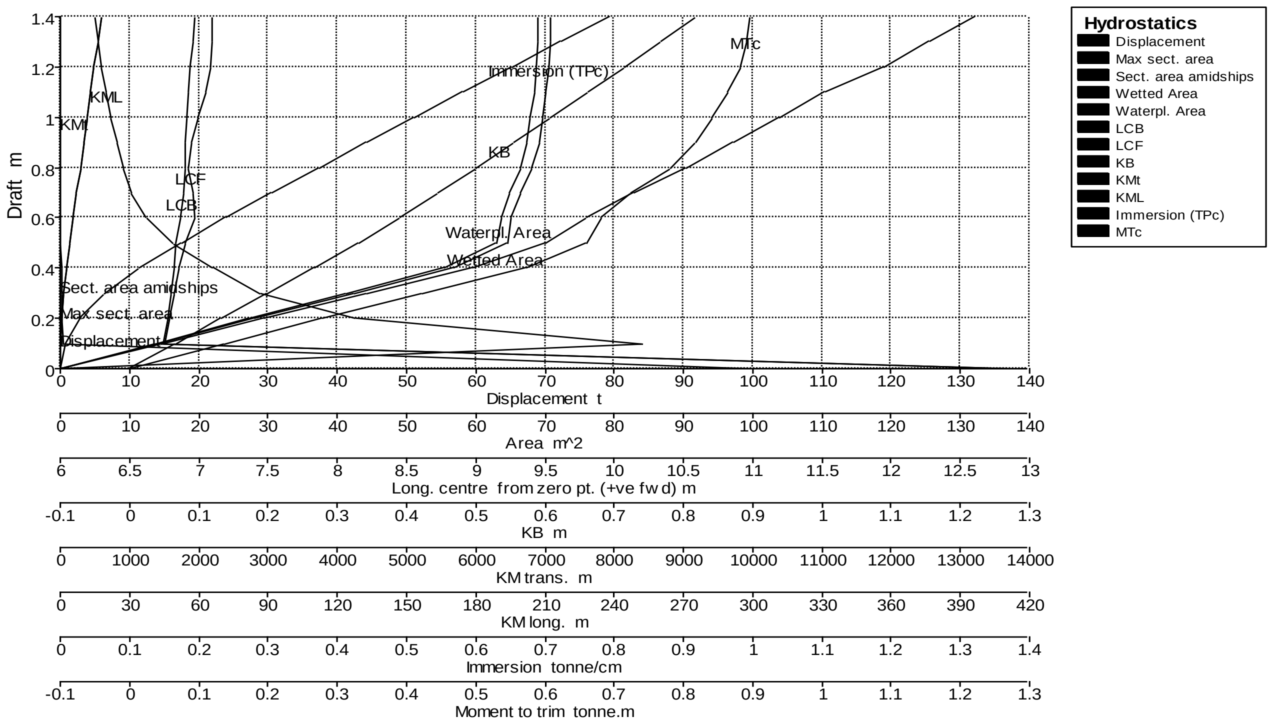


Fig. 5.
Graphic representation of hydrostatic data
Source: Results taken by us in Maxsurf and Hydromax program

3.2. Stability DATA

Stability data are calculated with the help of Maxsurf and Hydromax Software (Bentley, 2009), (Lapa, 2015), (Lapa, 2016). Here we present only the diagram KN depending on displacement Δ for any heel angle φ. Also it is presented graphically the static stability curve of the hull in the right position of the ship taken in the study.

Table 2
KN in different heel angles of "ALMARINA" pontoon

Displacement (t)	KN in different heel angles									
	0	10	20	30	40	50	60	70	80	90
5	1,837	2,022	2,103	2,108	2,028	1,864	1,619	1,299	0,926	1,837
10	1,806	1,977	2,051	2,051	1,99	1,832	1,582	1,265	0,901	1,806
15	1,594	1,939	2,027	2,033	1,939	1,761	1,519	1,219	0,875	1,594
20	1,372	1,905	2,006	1,991	1,882	1,701	1,462	1,174	0,851	1,372

25	1,21	1,875	1,961	1,932	1,822	1,648	1,418	1,143	0,833	1,21
30	1,09	1,814	1,895	1,863	1,759	1,596	1,38	1,122	0,829	1,09
35	0,995	1,653	1,824	1,786	1,692	1,543	1,345	1,105	0,832	0,995
40	0,914	1,501	1,699	1,708	1,628	1,494	1,313	1,093	0,841	0,914
45	0,844	1,352	1,518	1,55	1,497	1,395	1,251	1,068	0,851	0,844
50	0,783	1,203	1,336	1,365	1,351	1,289	1,181	1,034	0,854	0,783
55	0,717	1,051	1,161	1,213	1,221	1,185	1,109	0,997	0,852	0,717
60	0,641	0,895	1,01	1,078	1,103	1,09	1,04	0,958	0,847	0,641
65	0,552	0,744	0,872	0,952	0,994	1,002	0,978	0,923	0,84	0,552
70	0,449	0,613	0,739	0,831	0,891	0,92	0,921	0,892	0,837	0,449
75	0,336	0,488	0,612	0,713	0,791	0,843	0,868	0,866	0,838	0,336

Source: Results taken by us in Maxsurf and Hydromax program

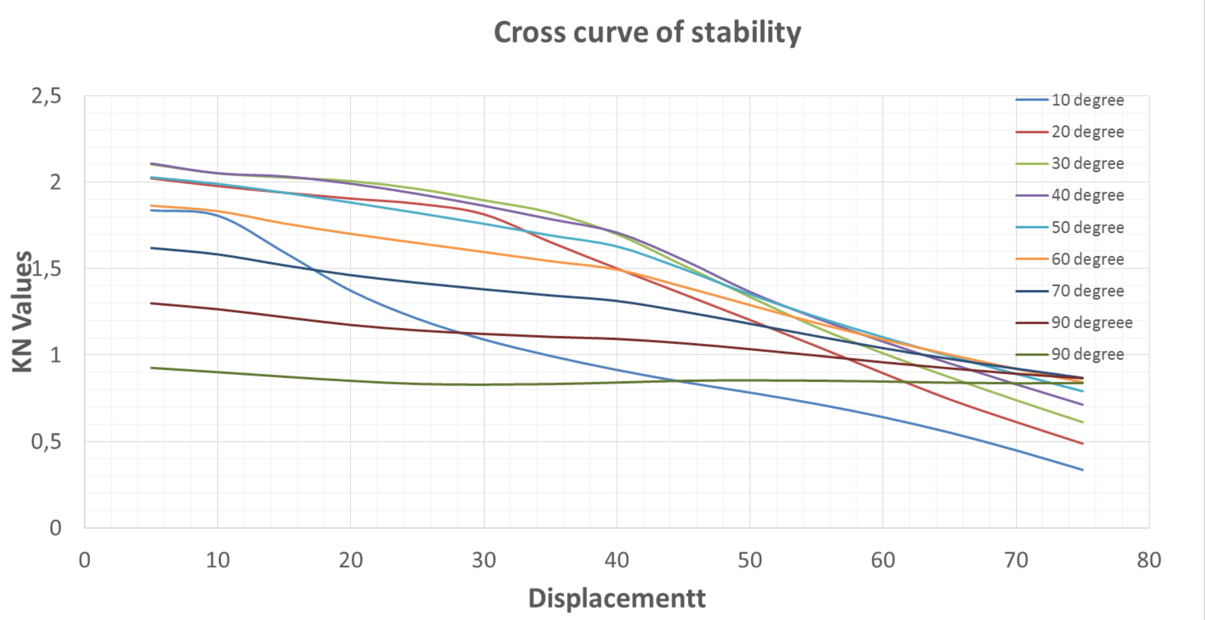


Fig. 6.
Graphic representation of Cross curve of stability
Source: Results taken by us in Maxsurf and Hydromax program and the graphic representation in Excel

3.3. Instruction to master for the use of cross curves of stability

The purpose of the cross curves is to enable Statical Stability Curves to be drawn (Bentley, 2009) for the ship in any sailing condition.
The righting lever can be calculated as follow:

$$GZ = KN - (KG \times \sin\varphi)$$

where:

- KN – Form Stability lever (see fig. 6)
- KG – Vertical position of center of gravity

φ - Angle of inclination

3.4. Calculation of the vertical center of gravity of the ship with 15 t cargo on main deck

Table 3
Weight Items and their vertical gravity center of "ALMARINA" pontoon (Lapa, 2003), (Lapa, 2004)

Nr	Weight Items	Weight (t)	VCG of weights Zi (m)	Moment about XY $M_{XY} = P*z$
1	Hull	17.341	0.5	8.6705
2	Crane	2	3	6
3	Crane engine	0.3	1.7	0.51
4	Crane basement	2	1.55	3.1
5	Planks of main deck	1.5	1.48	2.22
6	Main Engine	0.6	1.3	0.78

7	Outfits	0.2	0.75	0.15
	Lightship	23,941	VCG of Lightship condition	21.4305
			z	0.895138
8	Fuels	0.4	1.7	0.68
9	Cargo weight	15	1.8	27
10	Crew weight	0.24	1.95	0.468
11	DWT	0.4	1.7	0.68
	Total Weight	Σ1 = 39,341	=	Σ2 =49,5785
				1,26

Source: Results taken by us in Maxsurf and Hydromax program

Vertical center of gravity of ship:

$$KG = \frac{\Sigma_2}{\Sigma_1} = \frac{49.5785}{39,341} = 1.26\ m$$

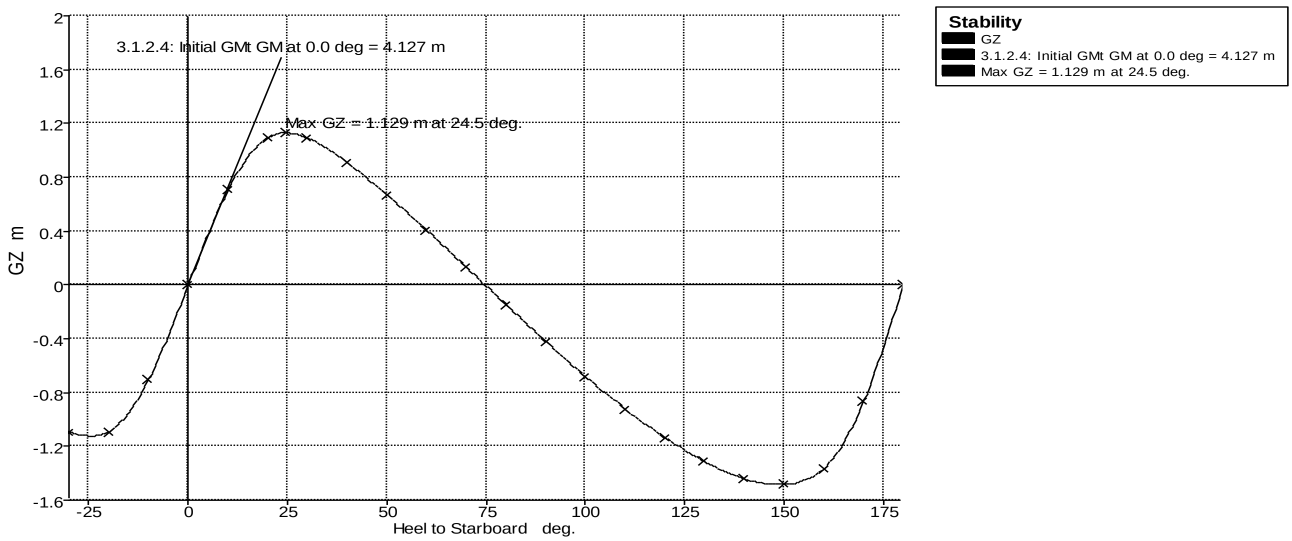
For the calculation of the ship's vertical center of gravity a weight of 75 kg is assumed for crew member. In this condition we have taken into consideration that the height of the cargo from the main deck does not exceed the value of 0.70m.

3.5. Stability data for 15 t cargo on the main deck

Table 4
Stability DATA of "ALMARINA" pontoon (Bentley, 2009), (Lapa, 2003)

Heel to Starboard deg	0.00	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00
GZ m	0.00	0.71	1.09	1.09	0.91	0.67	0.41	0.13	-0.15	-0.42
Area under GZ curve from zero heel m.deg	0.00	3.68	13.01	24.17	34.27	42.21	47.62	50.33	50.26	47.41
Displacement t	39.30	39.30	39.30	39.30	39.30	39.30	39.30	39.30	39.30	39.30
Draft at FP m	0.83	0.82	0.77	0.73	0.53	0.22	-0.15	-0.76	-2.48	n/a
Draft at AP m	0.83	0.82	0.79	0.84	0.89	0.88	0.74	0.44	-0.34	n/a
WL Length m	13.90	14.27	14.30	14.30	14.30	14.31	14.31	14.31	14.31	14.30
Beam max extents on WL (m)	5.50	5.37	3.92	2.78	1.81	1.37	1.20	1.11	1.09	1.11
Wetted Area m^2	92.45	90.28	92.62	93.36	86.25	84.39	83.84	83.20	82.41	81.66
Waterpl. Area m^2	66.87	64.15	44.23	26.41	13.44	10.55	10.77	11.58	12.58	13.67
Prismatic coeff. (Cp)	0.92	0.90	0.90	0.90	0.86	0.85	0.86	0.87	0.88	0.88
Block coeff. (Cb)	0.61	0.52	0.63	0.71	1.00	1.00	0.92	0.94	0.96	0.96
LCB from zero pt. (+ve fwd) m	6.90	6.90	6.90	6.89	6.87	6.86	6.85	6.85	6.86	6.86
LCF from zero pt. (+ve fwd) m	6.91	7.00	7.04	6.90	7.07	8.14	8.31	8.05	7.61	7.17

Source: Results taken by us in Maxsurf and Hydromax program



P.S.: The value of max GZ =1.129 m continues as a horizontal line up to 25.5 degree.

Fig. 7.
Graphic representation of stability arm GZ versus heel angel φ
Source: Results taken by us in Maxsurf and Hydromax program

After drafting the diagram of stability for the pontoon type marine vehicle, it is necessary to verify the IMO criteria for stability and the results are shown in the following table:

Table 5
Verification of stability of the ship under IMO criteria of "ALMARINA" Pontoon (Bentley, 2009), (Lapa, 2004)

Code	Criteria	Value	Units	Actual	Status	Margin %
A.749(18) Ch3 - Design criteria applicable to all ships	3.1.2.1: Area 0 to 30	3,15	m.deg	24,17	Pass	+667
	3.1.2.1: Area 0 to 40	5,16	m.deg	34,27	Pass	+565
	3.1.2.1: Area 30 to 40	1,72	m.deg	10,10	Pass	+488
	3.1.2.2: Max GZ at 30 or greater	0,20	m	1,10	Pass	+446
	3.1.2.3: Angle of maximum GZ	25,00	deg	24,50 -25,50	Pass	+1,82
	3.1.2.4: Initial GMt	0,15	m	4,13	Pass	+2651

Source: Results taken by us in Maxsurf and Hydromax program

3.6. Weather criteria (wind and rolling criterion)

The ability of a ship to withstand the combined effects of beam wind and rolling shall be demonstrated with reference to the following figure and under these circumstances, area b shall be equal to or greater than area a,

$$\frac{S_b}{S_a} = 2.84 > 1$$

as indicated in the following figure below (Lapa, 2004), (Lapa, 2005):

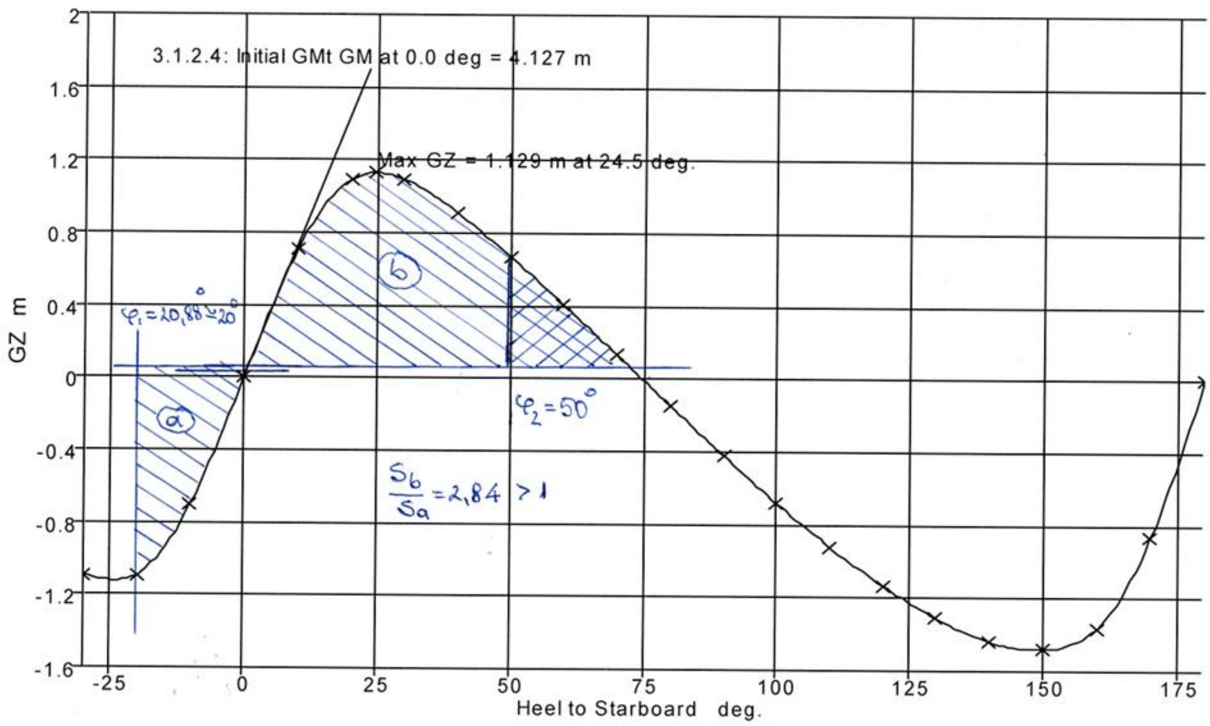


Fig. 8.
Severe wind and rolling
Source: Results taken by us

where the angles in this are defined as follows:

φ_0 = angle of heel under action of steady wind
φ_1 = angle of roll to windward due to wave action
φ_2 = angle of down-flooding or 50^0, whichever is less,

The wind heeling levers Iw1 and Iw2 are constant values at all angles of inclination and shall be calculated as follows:

$$I_{w1} = \frac{P \cdot A \cdot Z}{1000 \cdot 9.81 \cdot \Delta} = \frac{0.504 \cdot 22.204 \cdot 0.972}{1000 \cdot 9.81 \cdot 39{,}341} = 0.0281 m$$

where:

P = wind pressure of 504 Pa.

A = projected lateral area of the portion of the ship and deck cargo above the waterline = 22,204 (m^2)

Z = vertical distance from the center of A to the center of the underwater lateral area or approximately to a point at one half the mean draught =0.972 (m)

Δ = displacement = 39,341 (t)

g = gravitational acceleration of 9.81 m/s^2.

$$I_{W2} = 1.5 \cdot I_{W1} = 1.5 \cdot 0.0281 = 0.042m$$

The angle of roll (φ_1) shall be calculated as follows:

$$\varphi_1 = 109k \cdot X_1 \cdot X_2 \cdot (r \cdot s)^{0.5} = 109 \cdot 1 \cdot 0.80 \cdot 0.75 \cdot (1.019 \cdot 0.1)^{0.5} = 20.88^0$$

4. Conclusion

The marine vehicle pontoon type ALMARINA was built in the shipyard of Pashaliman.

Calculations were made for the completion of necessary technical documentation at Albanian Shipping Register after the pontoon was built.

It is shown that IMO stability criteria are fulfilled with an increased rate of stability, with the exception of GZ_{max} value.

The full procedure is indicated for stability calculations of the pontoon combined with the data obtained from drawings and verifications by direct measurements and the help of computer programs.

Maxsurf packages once again show its credibility in carrying out these calculations.

The results obtained may also serve to further studies and assessments related to this type of floating Pontoon type or in other similar cases.

References

AMA - Albanian Maritime Administration. 2009. *Albanian Regulation for Ship Inspection*. Durres, AL: AMA.

Bentley. 2009. *Maxsurf.* Australia: Formation Design Systems Pty Ltd.

Lapa K. 2003. *Ship Geometry*. Tirana, AL: SHBLU.

Lapa K. 2004. *Ship Hydrostatic and Stability*. Tirana, AL: SHBLU.

Xhaferaj, B. et al. 2010. *Design of hull surface using modern modeling technique*. The acts 2010, III(2): 260-266.

Lapa, K. et al. 2005. The influence of Albanian sea winds on fishing-boat stability of FV 2KP-400 type. In *Proceedings of the 11th International Congress of IMAM 2005*, Lisbon, 1231-1237.

Xhaferaj, B. et al. 2008. Using of Maxsurf software systems for assessing of navigation safety of marine vehicles in Albanian Maritime Transport. In *Proceedings of the Scientific Symposium "The credibility of the Maritime transport Vehicles"*, Vlora, 52-61.

Lapa, K. et al. 2015. A case study on the stability analysis of passenger ship in Lake Koman in Albania. In *Proceedings of the 17th International Conference on Transport Science of ICTS 2015*, Portoroz, 200-210.

Lapa, K. et al. 2016. Evaluation of stability for a passenger ship in inland water in Koman Lake in Albania. In *Proceedings of the 7th International Conference on Maritime Transport of MT 2016*, Barcelona, 319-328.

CARGO CONTAINERISATION AND ITS IMPACT ON THE DEVELOPMENT OF MARITIME TRANSPORT

Andrej Dávid[1], Peter Piala[2], Vlatka Stupalo[3]

[1,2] Department of Water Transport, University of Žilina, Žilina, Slovakia
[3] Department of Water Transport, University of Zagreb, Zagreb, Croatia

Abstract: Cargo containerization belongs to the most significant changes that happened in maritime transport in the 20th century. Containers not only reduce loading time in sea ports; but they also help to protect cargo against its damage, loss and theft. The first commercial transport of containers was carried out 60 years ago. In April 1956 the Ideal X, the converted tanker from the Second World War, transported them on her deck along the East Coast of the USA. Nowadays different types of containers are transported by cellular container ships which are divided into the generations according to their dimensions and transport capacity. In maritime transport there are three main container trade routes which link the developed to developing countries located in Asia, Europe and America. Sea ports are the gateways for all kind of cargoes which are transported by ships between the continents. In the world there are about 400 sea ports which transship containers in their container terminals. Twenty top world container ports transship about 50 % of a whole container port throughout the world. Most of them are located in Asia. Handling devices of terminals move and handle containers; they also transship them between different means of transport before they are forwarded to their final destination. Container terminals differ from one another in the way that they handle equipment and systems. Some of them have used the innovation technologies to increase their throughput such as automated handling equipment, double or triple spreaders.

Keywords: cargo containerization, containers, vessels.

1. Introduction

Throughout history, maritime transport has always played an important role in cargo transport between the continents. Cargo transport has been speeded up as the result of cargo containerization since the1950s. Nowadays, most general cargoes are transported into these transport units. Before the launching of containerization, most cargoes had been carried by port workers on dry cargo vessels which had transported them to other sea ports. The basic goal of the paper is to focus on the changes which have happened in maritime transport as the result of cargo containerization, such as the construction of vessels, maritime canals, container terminals, their handling equipment and systems.

2. The Status Quo of Maritime Transport and Containers

2.1. The Main Container Trade Routes

In maritime transport, there are three main container trade routes: the Transatlantic, Transpacific, and Europe – Asia (Figure 1). They link the developed to developing countries in the world and enable cargo exchange.
The first regular container transport started between North America and Europe in the mid-1960s (Stopford, M.). Local war conflicts in the world, world economic crises, piracy or the movement of subsidiaries of transnational companies from developed to developing countries may cause the changes in the direction or the volume of transport flows.

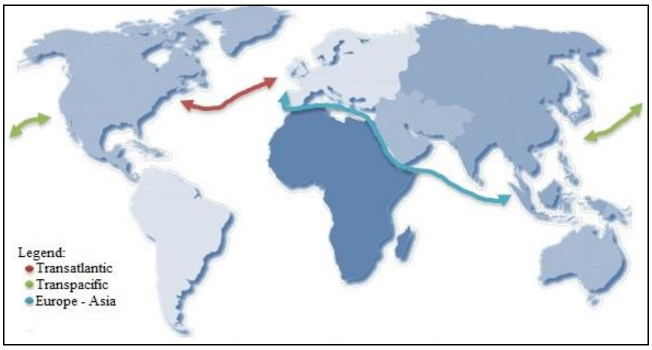


Fig. 1.
The main container trade routes
Source: authors

In 2014 most containers were transported between Europe and Asia (Table 1). Import to Europe was about 15.4 million TEUs, while export from Europe was about 7.0 million TEUs. On the container trade routes, significant imbalances have existed in export and import of containers which may influence on the prize for transport. In the same year, import of containers from North America to Asia (Transpacific route) was 14.7 million TEUs, while export was only 33.8 %

[1] Corresponding author: andrej.david@fpedas.uniza.sk

(7.5 million TEUs). The least amount of containers was transported between North America and Europe. (Review of Maritime Transport 2015)

Table 1
Transport of containers on the main container trade routes between 2012 and 2014 (estimated numbers)

year	Transatlantic		Europe – Asia		Transpacific	
	Asia to North America	North America to Asia	Asia to Europe	Europe to Asia	Europe to North America	North America to Europe
2012	13,1	6,9	13,7	6,3	3,6	2,7
2013	13,8	7,9	14,3	6,9	3,6	2,7
2014	14,7	7,5	15,4	7,0	3,9	2,7

Source: Review of Maritime Transport 2015

2.2. Top 20 World Container Ports

Nowadays there are approximately 400 world container ports that handle containers; the top 60 ports handle about 98 per cent of world container port throughput. Many countries have only one or two major container ports servicing the deep-sea trades, which are supported by a range of smaller ports handling short-sea and distribution trade. (Stopford, M.), (Grobarcikova, A., Sosedova, J.)
In 2014, the top 20 world container ports handled about 45.7 per cent of world container port throughput. It was about 310.116 million TEUs. These ports showed a 4.5 per cent increase in throughput compared to 2013. Between the top 20 world container ports there were sixteen Asian ports, three European ports and one American port. The port of Shanghai which was the world´s busiest container port was followed by Singapore and Shenzhen. The port of Rotterdam was the busiest European sea port; the port of Hamburg and the port of Antwerp followed it. In America, the port of Los Angeles was the busiest port. (Review of Maritime Transport 2015), (Jagelčák, J., Dávid, A., Rožek, P.), (Gašparík, J., Abramović, B., Halas, M.), (Mašek, J. et al.)

Fig. 2.
The busiest container ports in the world
Source: Port of Rotterdam

2.3. The Container Ships and their Development

Containers are transported by container vessels which are divided into generations according to their transport capacity and dimensions.
The first container ships appeared in the USA in the 1950s. Converted tankers from WWII transported containers on deck along the East Coast of the USA. In that time there was no special handling equipment that moved containers between vessels and sea ports. All handling operations were carried out by onboard or port cranes.
Due to the increase of cargo which was transported into containers, the second generation of container ships started to be built about a decade later. In the mid-1960s, these vessels started transporting containers between the East Coast of the USA and Western Europe. The last of them were cellular containers ships. Since then, each hold has had vertical rails called cell guides. In the hold containers can be stacked vertically. Depending on the size of the ship, they may be stacked up to 9 tiers below deck.
In the 1970s, shipyards started building another generation of container ships called Panamax. It was the last generation of container ships which could pass through old generation of lock chambers of the Panama Canal. The size limit of these locks chambers, which were built at the beginning of the 20th century by the USA, influenced on the dimensions of Panamax. Their deadweight was about 65 thousand tons. They could carry from 1 700 to 3 000 TEUs, out of which 8 tiers of containers below deck and up to 13 rows of containers on deck. The containers are handled between the vessel and the terminal by Panamax container gantry cranes. Their outreach is at least 35 meters.

Fig. 3.
Panamax Container Ship in the port of Koper
Source: Authors

The fourth generation of container ships, Post Panamax, was built in the 1980s, but could not pass through the Panama Canal due to their dimensions. Ships that used to transport containers between the Atlantic and the Pacific Ocean had to sail around Cape Horn. They could carry from 3 000 to 6 000 TEUs, out of which up to 9 tiers of containers below deck and 16 rows and up to 7 tiers of containers on deck. The outreach of Post Panamax gantry cranes which serve vessels is at least 45 metres.
In the 1990s, the fifth generation of container ships, called Super Post Panamax, started to be built. The vessels of this generation can only enter the ports which have deep water due to their draught. (Záležák, M.)
Ultra large container ships have been built since 2005. They may carry more than 9 000 TEUs (generally 12 – 14 000 TEUs). The length of ships is over 350 m, the draught is 14 – 15 metres, and they may transport 22 or 23 rows of containers and up to 7 tiers on deck. Their average speed is between 23 and 25 knots (40 – 50 kilometres per hour). The maximal seaward overhang of container gantry cranes that serve these vessels is at least 60 metres. (Široky, J.)

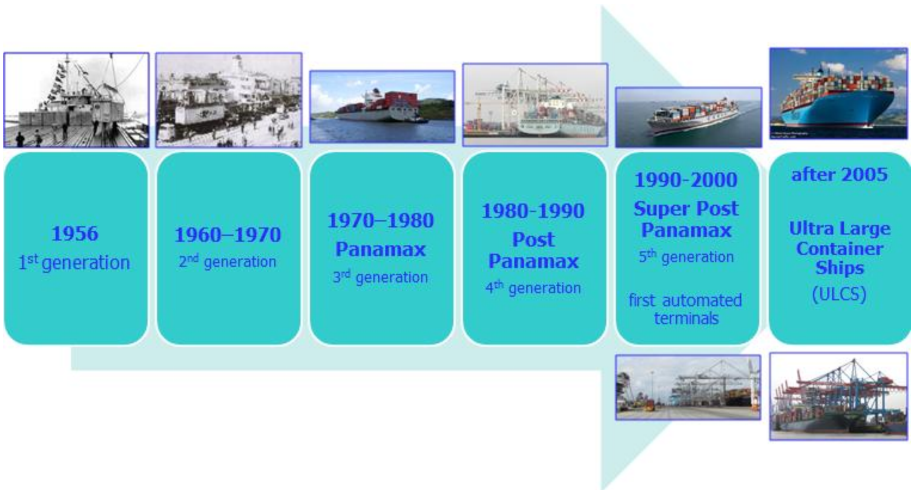


Fig. 4.
The development of container ships and terminals
Source: Authors

2.4. The Strategic Maritime Canals and Straits

In maritime transport there are several strategic canals and straits that are important for maritime transport.
The Panama Canal, which is located in Panama, shortens the distance between the Atlantic and the Pacific Oceans in about 7 000 – 9 000 miles. It is about 80 km long and was opened for maritime transport on 14 August 1914.
The Panama Canal has been managed by Panama since 1999. Nowadays between 13 and 14 thousand of vessels pass through the Canal every year which carry about 300 million tons of cargoes. Most of these vessels come from the USA and China.
In 2006 Panama decided to expand the Panama Canal because of the increase of its throughput. In 2015 new generations of lock chambers with reutilization basins were completed on both sides of the Canal. A new generation of container ships, New Panamax, has been able to sail through the Canal since 26 June 2016. These ships are much bigger and can carry more containers than Panamax. (Panama Canal Authority)
The Suez Canal provides a much shorter route between the North Atlantic and the Indian Ocean than the alternative route round the Cape of Good Hope. It links the Mediterranean Sea at Port Said with the Red Sea at Suez. The Canal,

which is the longest canal without locks in the world, is approximately 193 km long. It was opened for international navigation in 1869 after 10 years of construction.
The term Suezmax is used for ships that can sail through the Canal. Their deadweight is from 125 thousand to 240 thousand tons and their maximal width is 46 metres. Since its opening in 1869 it has been closed twice because of two war conflicts: the Suez Crisis (1956 - 1957) and the Six Day War (1967-1975). During its closing, tankers had to sail around the Cape of Good Hope and shipyards started building ultra large crude carriers.
The Suez Canal has been managed by Egypt since its nationalization between 1956 and 1957. (Suez Canal Authority)
The Kiel Canal connects the river Elbe at Brunsbüttel (the North Sea) with Kiel Fjord at Kiel-Holtenau (the Baltic Sea). It shortens the distance between the North Sea and the Baltic about 250 miles than the alternative route round the Jutland Peninsula. This canal is very important for feeder vessels that carry cargo between the port of Hamburg and the Scandinavian or Baltic States. Its length is about 98 km and has got two lock chambers. (Kiel Canal)
The Strait of Malacca belongs to the busiest and the most important waterways in the world. It links the Indian Ocean and the South China Sea and runs between Sumatra Inland and the Peninsula of Malaysia. Over 50,000 vessels (container vessels, tankers and bulk carriers) pass through the Strait per year, which transport raw materials such as coal, iron ore to manufacturing areas in Southeast and Northeast Asia. About a quarter of all oil carried by sea passes through the strait, mainly from the suppliers of the Persian Gulf to Asian markets such as China, Japan, and South Korea. The Strait is about 500 miles (800 km) long but it is very narrow and shallow. The term Malaccamax is used for ships which can sail through the Strait of Malacca. The limitation for these vessels is their draught. The Strait of Malacca belongs to the most vulnerable places in maritime transport due to attacks of pirates. (Široký, J.)

2.5. Container terminals and its basic parts

Container terminals are facilities where containers are loaded, unloaded, handled and transferred by different types of container handling equipment between different means of transport. They are also stored in an open-air storage area for a few days before they are forwarded by sea or land transport to their customers. (Tsinker, G.)
The land of the container terminal may be divided into three parts: the water side transfer area, the container yard and the land side transfer area.
The water side transfer area is the land of the container terminal from the wharf to the container yard. It is equipped by Post Panamax or Super Post Panamax container gantry cranes which transfer containers between a ship and the terminal. The different means of equipment (tractor with semi-trailer and truck trailer, straddle carrier, reach stackers, AGVs) transport containers between the water side transfer area and the container yard
The container yard is used for storage of containers which takes between 3 and 5 days (Agershou, H.). It is divided into the blocks that are located perpendicular or parallel to the wharf. Each block is equipped by at least two automated gantry cranes on rails that move containers within the block of yard or between the block and other parts of the terminal. The terminals that do not use automated handling equipment have got the blocks of container yard located parallel to the wharf. The blocks are equipped by gantry cranes on tyres which do the same function as automated gantry cranes on rails in the automated container terminals. Their advantage is that they may move from one block to another.
In the land side transfer area containers are transferred between means of road and rail transport by rail mounted gantry cranes. Wagons or tractors with semi-trailers transport containers between the terminal and the hinterland.

2.5.1. Handling equipment of container terminals

Container handling equipment can be divided into two categories:
1. Equipment that moves containers between the vessel and the terminal such as gantry container cranes. These cranes belong to the most widespread equipment in the world container sea ports. They can serve specialized container vessels that anchor at the wharf.
2. Equipment that moves containers within the terminal. Different types of equipment are used for handling containers within the terminal. Straddle carriers, automated guided vehicles or tractors towing trailers transfer containers between the wharf and the container yard. Within the terminal straddle carriers, rubber-tired or rail-mounted gantry cranes can carry out stacking or unstacking of containers. Tractor-trailer systems may be involved in receipt-delivery operations. (Tsinker, G.)

2.6. Automated container terminals

Automated container terminals are terminals in which some container handling equipment operates without direct human interaction. Drivers of the cranes have been physically removed, or they have remained in their cabins, but they are not needed for the entire duty cycle (Port of Los Angeles Automated Container Terminal Survey).
These terminals use some automated handling equipment such as automated guided vehicles, different automated stacking cranes or automated straddle carriers that:

- Transport containers at the water side transfer area from the wharf and to the container yard (automated guided vehicles, automated straddle carriers),

- Move containers between the water side transfer area and the container yard, the container yard and the land side transfer area and within the blocks of the container yard (different automated stacking cranes, automated straddle carriers),
- Transfer containers at the railway station located at the land side transfer area between semi-trailers and wagons (rail-mounted gantry cranes).

Automated container terminals differ one from another in reference to their level of automation, the type of handling equipment and system. Some of them use only automated handling equipment at container yards (Total Terminal International in the port of Algeciras). Automated stacking cranes (automated rail-mounted gantry cranes or rubber-tired gantry cranes) move and stack containers into the blocks of container yards. They also transfer containers between handling equipment that is located at the water or land side transfer area and the container yard.
More modern automated container terminals also use automated handling equipment at the water and land side transfer area (Container Terminal Altenwerder in the port of Hamburg). Automated guided vehicles or automated straddle carriers that are located at the water side transfer area transport containers between the wharf and the blocks of container yards. Automated / semi-automated stacking cranes that are located at the railway station at the land side transfer area, transfer containers between means of transport such as road and railway transport.

Fig. 5.
Automated Container Terminal Altenwerder in the port of Hamburg
Source: Authors

2.7. New ways of increasing throughput in the world container ports

The throughput belongs to the most significant indicators of world container ports. It is defined as the maximal volume of containers which is transferred by handling equipment of port between different means of transport for the monitoring period. It depends on technical equipment of sea port, transhipment technology, the type of containers, dimensions of container vessels, and other means of transport. (Záležák, M.)
The throughput is reduced by different downtimes that arise during transhipment of containers. These downtimes follow from the breakdown rate of handling equipment, their technical breaks and auxiliary operations related to vessels such as anchoring and cargo inspection.
The world container ports have used different methods to increase their throughput:

1. The increase in the number of container gantry cranes (cranes) which serve container ships. This system was used in the container terminal Ceres located in Amsterdam. The cranes located on both side of the basin used to transfer containers between a vessel and the terminal. According to the calculation transhipment was reduced to about 50 %,
2. Automation of handling processes. This system has been used in the world container ports more than 20 years. ECT Delta Terminal located in the port of Rotterdam was the first terminal in the world that started using automated guided vehicles at water side transfer area. Automated stacking cranes, automated guided vehicles and automated straddle carriers have replaced handling devices controlled by port operators. Their movement within the terminal is controlled by port computers (Kolarovszki, P. 2016. et al.),
3. The increase in the number of containers that are transhipped in an operating cycle. The first container gantry cranes used to tranship the only one container in an operating cycle. Nowadays, some cranes can handle from 2 to 6 TEUs or from 1 to 3 FEUs in an operating cycle. They use double or triple twin-lift spreaders. They can be found in some Asian ports such us the port of Shenzhen or the port of Dubai. Some container gantry cranes use two trolleys. The first trolley (water side trolley) tranships containers between a container and the platform

which is located inside of the portal of crane. The second trolley (land side trolley) handles containers between the platform and the apron. Loading / unloading time is reduced about 30 and 40 per cent.

3. Conclusion

The basic goal of the paper was to focus on the changes which have happened in maritime transport as the result of cargo containerization. On one hand these changes have influenced the construction of faster and bigger container ships which enable to transport at least 10 thousand TEUs per journey between the continents, on the other hand they have also affected on the widening of the dimensions of maritime canals and straits. The increased turnover of containers in the world container ports in the last few years has caused the changes in the construction of container terminals, their handling equipment and systems. Some world container ports are building the automated container terminals which will be equipped by the latest generation of container gantry cranes and other automated handling equipment. On one hand, this automated handling equipment will enable faster handling operations in the container terminals which will influence the throughput of container terminals; on the other hand, they will reduce the amount of time that the vessels spend at the ports and the staff costs of ports workers including the costs for transshipment operations.

Acknowledgements

This paper presents results of work supported by the Slovak Scientific Grant Agency of the Slovak Republic under the project VEGA No. 1/0331/14: Modelling of Distribution Logistics System with Using Software Solutions. Faculty of Operation and Economics of Transport and Communications, University of Zilina.

References

Agershou, H. 2004. *Planning and Design of Ports and Marine Terminals*, Thomas Telford Publishing, London, UK.
Gašparík, J.; Abramović, B.; Halas, M. 2015. New graphical approach to railway infrastructure capacity analysis, *Promet – Traffic & Transportation*, 27(4): 283-290.
Grobarcikova, A.; Sosedova, J. 2015. Transportation of containers using the inland waterways. In CER Comparative European research 2015. In *Proceedings of the Research Track of the 4th Biannual CER Comparative European Research Conference*.
Jagelčák, J.; Dávid, A.; Rožek, P. 2010. *The Maritime Containers* , EDIS, Zilina, Slovakia.
Kiel Canal 2016. Available from Internet: <http://www.kiel-canal.org/english.htm>.
Kolarovszki, P.; Tengler, J.; Perakovic, D.; Perisa, M. 2016. Impact of sorting machine of life cycle of passive UHF RFID tags placed on letter mail, *Communications: scientific letters of the University of Žilina*,18(2): 143-147.
Mašek, J.; Juraj Čamaj, J.; Milinković, S.; Vesković, S.; Kendra, M. 2015. Proposal and application of methodology of revitalisation of regional railway track in Slovakia and Serbia: Part 2: State of regional transport in Slovakia and Serbia, *Transport Problems*, 10(4): 107-119.
Oakland 2012. Port of Los Angeles Automated Container Terminal Survey Available from Internet: <https://www.portoflosangeles.org/Board/2012/May%202012/POLA-Automation-Survey-Draft.pdf>.
Panama Canal Authority 2016. Available from Internet: <https://www.pancanal.com/eng/>.
Port of Rotterdam 2016. Available from Internet: <https://www.portofrotterdam.com/>.
Review of Maritime Transport 2015. Available from Internet: <http://unctad.org>.
Rodrigue, J. 2013. *The Geography of Transport Systems*, Routledge, New York, U.S.A.
Široký, J. 2010. *The Progressive Systems in Combined Transport*, Pardubice University, Pardubice, Czech Republic.
Stopford, M. 2009. *Maritime Economics.* Routledge, Oxon, UK.
Suez Canal Authority 2016. Available from Internet:: <http://www.suezcanal.gov.eg/>.
Tsinker, G. 2004. *Port Engineering*, John Wiley and Sons, New Jersey, U.S.A.
Záležák, M.2001. *Technology in Ports and Transshipment Areas, 8 - Container Terminals.* EDIS - the publisher of the University of Zilina, Zilina, Slovakia.

THE STATUS OF VESSELS FOR SPORT AND RECREATION IN THE CROATIAN AND MONTENEGRIN LEGISLATION AND MEETING THE REQUIREMENTS OF NAVIGATION SAFETY IN NAUTICAL TOURISM PORTS

Ranka Petrinović[1],Nikola Mandić[2], Ena Sirišćević[3]
[1,2] Faculty of Maritime Studies, University of Split, Split, Croatia
[3] Faculty of Law, University of Split, Split, Croatia

Abstract: Nautical tourism on the Adriatic Sea represents a particularly significant sector of maritime and tourist activities. The safety of sport and pleasure boats guarantees successful performance of nautical tourism activities. An increasing number of these boats sailing in the Adriatic Sea is important for the overall economic development of the Republic of Croatia and the Republic of Montenegro. In Croatia, sport and pleasure boats are regulated by the Maritime Code, the Ordinance on Boats and Yachts and a number of subordinate legislation acts, while in Montenegro they are regulated by the Law on Yachts, the Law on Safety of Maritime Navigation, the Regulation on Boats and other subordinate legislation. These regulations govern the conditions for navigation, the area of navigation, seaworthiness of yachts and boats, procedure and conditions for acquiring qualifications and certificates for boat leaders, yacht masters and skippers. This paper puts special emphasis on regulatory laws on yachts, sport and pleasure boats, as well as on requirements that must be met in ensuring the safety of navigation. According to the broadest definition, a yacht is a boat designed and equipped for long sea voyages, and it is used for sport and pleasure. However, more detailed analysis indicates inconsistency in legislative terminology of the two systems, such as the definition of the term "yacht". The same applies to the term "boat". It can therefore be concluded that there are certain differences in the Croatian and Montenegrin legislation, and in this respect the paper will also provide *de lege ferenda* solutions.

Keywords: sport and pleasure boats, yachts, sailing vessels, nautical tourism, nautical tourism ports, safety of navigation.

1. Introduction

The Adriatic Sea is a bay deeply cut into the mainland of the Mediterranean between the Balkan and the Apennine peninsulas stretching in the south-east and north-east directions. It occupies an area of 138,595 km^2. The total length of coastline (mainland and islands) is 7912 km, and the indentation coefficient is 6.1. A part of the eastern Adriatic coast from the mouth of the river Dragonja to the middle of the entrance to the Bay of Kotor belongs to the Republic of Croatia, and the part of the coast from the middle of the entrance to the Bay of Kotor to the mouth of the river Bojana belongs to Montenegro.

Highly developed coast of Croatia is 5,835 km long, which is 74% of the total length of the Adriatic coast. There are 1,244 islands, islets and rocks and 4,398 km of the coastline length estimate belongs to the coastline of islands. The indentation coefficient of the Croatian coast is 11, which makes it one of the most indented coasts in the world. The total length of the Montenegrin coast is 260 km, which represents 3.3% of the total length of the Adriatic coast. Number of islands, islets and reefs is 48. The coefficient of indentation of the Montenegrin coast is 3. The surface area of the Croatian part of the Adriatic sea is 31,067 km^2, and of the Montenegrin part is 2099 km^2.

The Adriatic Sea affects a way of life which is very similar among the inhabitants of the coastal areas of Croatia, Montenegro, Italy and Albania. Regardless of the length of the coast, Croatian and Montenegrin coasts are considered to be very suitable for nautical tourism, a part of industry that contributes significantly to the economic development of both countries. Nautical tourism is a form of tourism with distinctive features which significantly distinguish it from other forms of tourism, and particularly because of the models of management of maritime domain and navigation safety systems at sea.

Nautical tourism means navigation and accommodation of tourists – navigators on cruising vessels and in nautical ports for the purpose of rest and recreation. Although nautical tourism is an integral part of the tourist industry, it is a highly interdisciplinary phenomenon and therefore, we can say that nautical tourism is an interdisciplinary tourist phenomenon containing a maritime component. (Luković et al., 2015) The essential difference between nautical tourism and other forms of tourism is in sailing and great mobility of nautical tourists, which involves frequent and often daily change of residence.

The positive effects of nautical tourism are of great importance in the development of the economy, not only for obvious economic effects, but also the fact that tourist consumption contributes considerably to the growth of relatively small national markets of Croatia and Montenegro enabling, so-called, *invisible exports*. In addition to all positive effects of nautical tourism there are negative ones which are reflected primarily in the use of external environment for infrastructure development, as well as short seasonal presence of a large number of tourists in a particular area and the increased number of sailing vessels, which enhances the number of maritime accidents during the summer months (*Development Strategy of Croatian Nautical Tourism*).

[1] Corresponding author: ranka@pfst.hr

2. Nautical tourism legislation

As stated at the beginning, nautical tourism is a part of the tourist industry with a significant maritime component. (Luković et al., 2015) In nautical tourism, tourist services are mainly provided in the ports of nautical tourism and on board nautical tourism vessels. The nautical tourism ports and waterborne craft are classified into types, and certain types are categorized. Different kinds of subordinate legislation govern the types and categories of nautical tourism ports and vessels, the minimum requirements to be met by such ports, as well as the categories and methods of categorization of ports and vessels of nautical tourism.
In Croatia, nautical tourism activities are governed by several laws and regulations. Two basic legal regulations are *the Maritime Code* and the *Act on the Provision of Tourism Services.* Apart from those, it is necessary to point out *the Maritime Domain and Seaports Act.* Subordinate legislation governing nautical tourism includes *the Ordinance on Boats and Yachts, the Ordinance on the Classification and Categorization of Nautical Tourism*, the *Ordinance on the Types and Categories of Vessels of Nautical Tourism, the Ordinance on the Conditions to be met by Vessels, and Natural or Legal Person Performing the Activity of Leasing Vessels, the Regulation on Conditions for Leasing Vessels with or without Crew and Offering Accommodation Service on board Vessels*, *the Regulation on the Classification of Ports Open for Public Transport and Ports for Special Use*, *the Decree on Conditions that Ports Must Meet* and *the Regulation on Conditions for the Arrival and Stay of Foreign Yachts and Boats Intended for Sport and Leisure in the Internal waters and Territorial Sea of the Republic of Croatia*.
In Montenegro activities in nautical tourism are also regulated by several laws and regulations. The main statutory requirements are *the Law on Yachts, Port Law, the Law on Maritime Domain, the Law of the Sea, the Law for the Prevention of Pollution from Ships and the Law on Safety of Maritime Navigation.* Subordinate legislation governing nautical tourism includes *Regulation on smaller boats, Regulation on Conditions that must be met by Ports Classified according to the type of Maritime Traffic* and *Purpose* and *the Decision* on *Determination of Ports according* to *Significance.*

3. Categorisation of ports and vessels of nautical tourism

As previously stated, the two basic components that make up the nautical tourism are the nautical tourism ports and nautical tourism vessels.

3.1. Nautical tourism ports

3.1.1. Croatia

According to Art. 2, para. 1, pt. 1 of *Maritime Domain and Seaports Act*, in the broadest sense, a port shall mean a seaport, i.e. water space and the land space with developed and undeveloped coast directly connected with sea space, as well as breakwaters, installations, plants and other facilities designed for landing, anchoring and protection of ships, yachts and carrier boats, embarkation and disembarkation of passengers, loading and unloading of goods, storage and other handling of goods, manufacturing, refinement and finishing of goods, as well as other economic activities in economic, traffic and technological relation with these activities.
Furthermore, according to their purpose, ports are divided into ports open for public transport and ports for special use. Both types of ports can be ports open for international transport and ports open for domestic transport. According to the activities carried out by the ports for special use they can be divided into: naval ports, nautical tourism ports, industrial ports, shipbuilding ports, as well as sports, fishing and other type of ports for similar purposes. By their importance for the Republic of Croatia, the special purpose ports are divided into: ports of importance for the Republic of Croatia, and ports of county importance.
Nautical tourism activities take place in the ports for special use primarily nautical tourism ports and ports intended for sports. A nautical port mainly serves for reception and accommodation of cruising vessels and it is equipped for provision of services to clients and vessels. From business, construction and functional aspects, it makes an integral whole. Nautical tourism ports are functional business units in which a legal or natural entity operates and provides tourist services in nautical tourism and other services in the area of tourist spending (trade, catering, etc.). Accordingly, the ports of nautical tourism are tourist facilities in which, apart from communication services, a variety of other additional services are provided, such as accommodation and catering for boaters, maintenance and repair of vessels, supply of spare parts, food and hygiene products supply, and recreational and all other services that navigators need. (Šamanović, 2002) Sports ports are ports used for berthing of sailing vessels registered in the Croatian Register of sailing vessels intended for sport and leisure, and owned by association members, or by the same association which has a concession contract for the port.
Nautical ports of importance for the Republic of Croatia are those that have a capacity of 200 berths and more, and those of importance to a county are the ones that have a capacity of up to 200 berths in the sea. Sports ports of importance for the Republic of Croatia are those that have a capacity of 200 berths and more, and of importance to a county are those that have a capacity of up to 200 berths.

Reception facilities for sailing vessels are located in nautical tourism ports and at nautical berths in the ports open to public transport. Nautical berths can be a year-round, seasonal and transit. Receiving capacity is on a year-round and seasonal basis. Boat reception services include leasing of permanent and transit berths.
The Regulation on Classification and Categorization of Ports for Nautical Tourism prescribes the types, minimum requirements, categories and method of categorization of nautical tourism ports. Nautical ports, according to the type of services they provide in the port, are divided into: anchorage, cruising boat storage, dry marinas and marinas. *Anchorage* is a part of the sea or water area suitable for anchoring of sailing vessels, equipped with equipment for safe anchoring. *Storage of sailing vessels* is a part of the land fenced and equipped for rendering services of sailing vessels storage on land, and the provision of services of transport of boats, their launching and taking out of the sea. This type of *Storage of sailing vessels* does not provide accommodation for tourists and it is not used for preparing sailing vessels for their voyages. *Dry marina* is an area fenced and arranged for providing the storage of sailing vessels on dry land and they also provide the services for their transport, launching and taking out of the sea. A *dry marina* type can offer accommodation to tourists, as well as services for preparing sailing vessels for their voyages. *Marina* is a part of water and shore area specially built and equipped for providing services of communication, accommodation of tourists on board sailing vessels and other services.
Marinas are the only type of nautical tourism ports that are categorized. The category of marina depends on the fulfilment of the conditions laid down for each category in the *The Regulation on Classification and Categorization of Ports for Nautical Tourism*: quality of equipment and facilities, standard of basic services, diversity of additional services offered to tourists at the marina, as well as other services and facilities at disposal to tourists in the immediate vicinity of the marina and the quality of maintenance of the marina as a whole. Marinas are awarded anchors for each category. They can have: two, three, four or five anchors.

3.1.2. Montenegro

According to Art. 4, par. 1, pt. 5 of *Law on ports*, a port is defined as the sea and a shore area directly connected to the sea with constructed and non constructed quays, piers, breakwaters, buildings, installations and facilities intended for the provision of port services and performance of other activities regarding the economic, traffic or technological matters. Furthermore, according to their purpose, ports can be divided into: commercial ports, nautical tourism ports - marinas, shipbuilding ports and fishing ports. According to the types of maritime transport, ports are divided into ports open for international and for domestic transport.
According to their significance, ports are divided into ports of national significance and ports of local significance. *The Decision* on *Determination* of *Ports according* to *Significance* individually determines the ports of national and of local significance.
The nautical tourism activities take place in the ports of nautical tourism - marinas. *Nautical tourism ports - marinas* are ports intended for accommodation, storage, protection, maintenance, repair, fitting out and mooring of yachts and smaller boats.
The Rulebook on Types of Nautical Tourism Facilities, Minimal Technical Conditions and their Categorization classifies the reception facilities of nautical tourism and divides them into marinas, ports and harbours, docks, berths and anchorages. *A marina* is the nautical tourism facility with naturally or artificially protected water (sea, lake and river) areas, specializing in providing communication, supply, storage, maintenance and repair of sailing vessels, catering services, boat rental services, as well as other services in accordance with the requirements and the specific needs of nautical tourists. *Ports, harbours and docks* area nautical tourism facilities that are wholly or partly designed and tailored specifically to the primary navigation needs of the nautical tourism sailing vessels (reception, berth and supply), as well as other basic living and service needs of nautical tourists (inspection and minor repairs on sailing vessels). *Berths* are specially constructed coast or the coast connected areas fitted out for reception and berthing of nautical tourism sailing vessels, with direct pedestrian access to the vessel. *Anchorages* are naturally or artificially protected sea, lake or river water area furnished and equipped with mooring gear for nautical tourism boats, without the possibility of pedestrian approach to the boat.
Of all nautical tourism reception facilities only marinas are subject to categorization. Marinas are classified according to the conditions that must be met regarding their design, equipment and types of services (mandatory elements), and other conditions and facilities at their disposal (optional elements). The classification of marinas into categories and category designation is done in a way that each single category is symbolically awarded a suitable number of boat propellers: five propellers are awarded to the first category marina, four propellers to the second category marina, three propellers to the third category marina, two propellers to the fourth category marina, and one propeller to the fifth category marina.

3.1.3. Comparative analysis

Contrary to classification of ports of nautical tourism in Croatia prescribed in *The Regulation on Classification and Categorization of Ports for Nautical Tourism,* in the publications on nautical ports, (anchorages, boat storages, dry marinas and marinas) are divided into anchorages, berths, dry marinas and marinas. Such a division is contained in *The Regulation on Classification and Categorization of Ports for Nautical Tourism* of 1999, which expired after adopting the new *Regulation* in 2008. However, the new *Regulation* in its transitional and final provisions stipulates that legal or natural persons who on the date of entry into force of the *Regulation*, have a trade license for the port of nautical tourism in accordance with the *Regulation* of 1999, are not obliged to align with the new *Regulation*, but they may apply for classification and categorization in accordance with the new *Regulation* of 2008. According to this provision, the most of nautical tourism ports are still categorized by the previously valid categorization. Therefore, the classification that is provided in the new *Regulation* of 2008 has not yet taken hold in practice. However, this fact is not damaging considering the vagueness that has been brought by the new *Regulation* of 2008. Instead of "berth" that *Regulation* cites "boat storage" which is by definition very similar to a dry marina. In fact, the only difference being that the boat storage is used for the storage of sailing vessels on land where tourists cannot stay, and where it is not possible to prepare the boats for navigation, while in dry marina it is possible for the tourists to store their sailing vessels, stay there, and prepare their sailing vessels for navigation. The above shows that there is no essential difference between the definitions of these two terms. The difference is not sufficiently significant to mean specific types of nautical tourism ports, and therefore, this division is unnecessary. Although the new *Regulation* of 2008 tries to distinguish between the two, we believe that this is unnecessary and impracticable. Thus, it has been proposed to amend this part of *the Regulation on the Classification and Categorization of Ports for Nautical Tourism* and to restore the categorization as in *the Regulation* of 1999.

The analysis of Montenegrin *Rulebook on types of nautical tourism facilities, minimal technical conditions and their categorization* shows a lack of precision in defining the harbours, docks and berths, and their classification criteria are not clear. Namely, in the division itself, harbours (together with ports) are listed separately from the docks, and where each term is being defined there is a combined definition for both, *harbour* and *dock*. Although in practice there might be reasons for distinguishing these concepts, they are not adequately highlighted in *the Regulation*. Furthermore, there is no mention of differences between *marinas* and *dry marinas*, which certainly needs to be mentioned with regard to the specific protection of the sailing vessels on land. Therefore, we believe it is necessary to adopt a new division, or amend the current one in a way that each type of reception facility for nautical tourism is adequately defined.

Legal regulation of marinas, which still are the most important part of nautical tourism, has been adjusted in an adequate manner in both countries. We may just point out that in the categorization of marinas, there are differences because Croatia categorizes marinas in four, and Montenegro in five categories. However, this does not seem to make a significant difference.

3.2. Vessels

In nautical tourism there are numerous vessels of different properties and uses. Cruise ships are included in nautical tourism vessels. However, these vessels are not the subject of analysis in this article.

The common feature of all vessels in nautical tourism is that they are intended for sport and recreation. In principle, the vessels in nautical tourism are not subject to the provisions of international conventions, but are subject to local regulations as far as the safety of navigation is concerned. Therefore, it is necessary to separately analyze the Croatian and Montenegrin regulations that conceptually define vessels in nautical tourism.

3.2.1. Croatia

According to Art. 5 of the *Maritime Code*, as the basic regulation in the domain of maritime law, vessels shall be classified as ships, warships, submarines, yachts and boats. Due to the specifics of nautical tourism it is necessary to highlight the concepts of ships, boats and yachts. *Ship* is a waterborne craft designed for sea navigation, 12 meters in length and a gross tonnage of more than 15 tons, or it is authorized to carry more than 12 passengers. *Yacht* is a waterborne craft for sports and recreation, regardless of whether it is used for personal needs or business, exceeding 12 m in length and intended for a longer stay at sea, which is furthermore authorised to carry no more than 12 passengers in addition to the crew. *Boat* is a waterborne craft intended for navigation at sea, which is not a ship or a yacht, and the length of which is more than 2.5 metres or the total power of its propulsion engines is greater than 5 kW. The term boat does not encompass: vessels belonging to another maritime craft for the purpose of collecting, salvaging or conducting work, vessels intended exclusively for competitions, canoes, kayaks, gondolas and pedal boats, windsurfing boards and surfboards. If the Maritime Code does not provide otherwise, its provisions relating to ships also apply to yachts.

According to the *Ordinance on Boats and Yachts* there is a more detailed classification of vessels in nautical tourism, based on the technological characteristics of the vessel. Therefore, we have boats for personal use, boats for commercial purposes, yachts for commercial purposes, yachts for personal purposes, pleasure boats and speedboats. *Boat for personal use* is a boat for sport and leisure that is not used for commercial purposes, while *boat for commercial purposes* is a boat for transport of passengers and / or freight against payment, recreational boats for leasing, professional fishing, extraction of gravel, stone and other economic activities. *Yacht for commercial purposes* is a yacht designed for leasing with or without crew, while *yacht for personal needs* is a yacht that is not used for commercial purposes. *Pleasure boat* is a vessel of any type intended for sports and leisure that has a hull length from 2.5 to 24 m measured according to agreed standards, regardless of the type of propulsion. *Speedboat* is a boat or a yacht that slides on the surface of the sea using a mechanical propulsion device.

According to the *Ordinance on the Types and Categories of Vessels of Nautical Tourism* a vessel of nautical tourism is a ship, a boat or a yacht designed and equipped to provide tourist services in nautical tourism. Furthermore, the same *Ordinance* states that the vessels of nautical tourism shall be classified according to the type of services they provide:

craft for excursions and cruising craft. *Craft for excursions* is intended for tourist transport services for excursions lasting up to 24 hours without accommodation services. *Cruising craft* is intended for tourist transport services of cruising lasting over 24 hours, equipped for days-long stays of tourists. The craft must meet the minimum requirements established by specific regulations regarding registration in the Croatian Register, as well as the conditions prescribed by the *Ordinance*.

Every year when processing the data on the capacity and operation of the nautical tourism ports, Croatian Central Bureau of Statistics divides the vessels for leisure and sports into yachts (motor and sailboats) and other vessels. *Motor yacht* is a vessel equipped with engine intended for leisure, sport or recreation, which is according to common maritime customs, equipped with a cabin with at least two beds, a toilet and cooking facilities. *Sailboat* is a vessel intended for leisure, sport or recreation whose main power is wind. It is equipped with a cabin with at least two beds, a toilet and cooking facilities. *Other vessels* are boats (wooden, plastic, rubber, etc.) of 3 meters or more in length, or less than 3 meters if they have an engine. Speedboats are also included into *other vessels* unless they qualify for yachts.

3.2.2. Montenegro

Article 2 of *the Law on Yachts*, provides definitions for yachts, foreign yachts, foreign smaller boats, yachts for economic activity and yachts for personal use. *Yacht* is a vessel driven by engine or sail power, which can have more than one hull, designed and equipped for days-long stay at sea for pleasure, sport and recreation. It is over 7 meters in length, and it is used for personal needs or economic activities. *Foreign yacht* means a yacht flying a foreign flag. *Foreign smaller boat* is a vessel that has a foreign flag. *Yacht for economic activity* is a yacht, or a foreign yacht intended for leasing with or without crew. *Yacht for personal use* is a yacht or a foreign yacht that is not used for economic activities. This regulation does not fully define the terms since it does not give the definition of *smaller boat*, and states that the foreign smaller boat is a craft with a foreign flag. Therefore, with regard to *the Law on Yachts*, the full meaning of the term "smaller boat" is unclear.

The Law of the Sea defines, among other terms, the terms *ship* and *foreign yacht*. *Ship* is a vessel designed for sea navigation, 12 meters in length and a gross tonnage of more than 15 tons, or it is fit to carry more than 12 passengers. *Foreign yacht* is a vessel that has a foreign flag, 7 meters in length, used for leisure, sport and recreation and is suitable for days-long stay at sea.

Article 6 of *the Law on Safety of Maritime Navigation* defines the terms: *ship, boat, smaller boat and yacht*. *Ship* is a vessel designed for navigation (passenger, cargo, technical craft, fishing, public or scientific research ships), whose length is more than 12 meters and a gross tonnage more than 15 tons, or carrying more than 12 passengers. *Boat* is a vessel designed for sea navigation, 7-12 meters in length and a gross tonnage of less than 15 tons with power of less than 75 kW and fit for days-long stay at sea. *Smaller boat* is a vessel designed for navigation at sea, which is neither a boat nor a yacht, whose length is more than 2.5 meters, with engine power greater than 5 kW, including the watercraft, jet-ski , etc. In addition to the lifeboats on the vessel and smaller boats for sport competitions (canoes, kayaks, gondolas and pedal boats, surfboards and windsurfing boards) and it is not fit for days-long stay at sea. *Yacht* is a vessel intended for leisure, sport and recreation, more than 7 meters in length, which is not engaged in international navigation.

In Article 2 of the *Regulation on Smaller Boats*, the terms defined, among others, are a *smaller marine boat, smaller boat for commercial purposes, smaller boat for personal needs, speedboat, smaller sails boat, and smaller rowing boat*. *Smaller marine boat* is a craft intended for navigation at sea, with less than 12 meters in length, and registered capacity of less than 15 gross tons. *Smaller boat for commercial purposes* is a boat for the transport of passengers and / or goods against payment, fishing, extraction of gravel, stone etc. *Smaller boat for personal needs* is a boat for leisure, sport and other non-economic purposes. *Speedboat* is any boat that uses a mechanical drive device to slide on the surface of the water. *Smaller sails boat* is any boat that uses sails with sufficient surface size to move through the water. *Smaller rowing boat* is any boat which is propelled by oars.

The Rulebook on Types of Nautical Tourism Facilities, Minimal Technical Conditions and their Categorization classifies the vessels in nautical tourism and divides them into recreational craft, excursion craft, tourist yachts and tourist craft for tourist cruises. *Recreational craft* is a craft that is propelled by human power, wind or engine, used for pleasure and sports and recreation on the local reception facility of nautical tourism (smaller boat, a boat with an engine, sailing boat, water bike, surfboards, water scooter etc.). *Excursion craft* is a smaller boat or a ship used to transport tourists or day cruises with excursion facilities (hydrofoil, a smaller boat with an engine or a smaller ship for day trips, tourist taxi). *Tourist yacht* is a vessel for a longer stay of boaters at sea, with a cabin equipped with at least two beds, a toilet and cooking facilities (engine-powered yacht, wind-powered yacht). *Craft for tourist cruises* is a vessel with a crew that carries tourists for sailing and cruising, and is equipped for longer stays of crew and tourists at sea.

Yachts and craft for tourist cruises are nautical tourism vessels that are subject to categorization. Nautical tourism vessels are categorized according to the conditions in terms of design, equipment and types of services they provide (mandatory elements), and other conditions and facilities at their disposal (optional items). Classifying vessels of nautical tourism into categories and category designation is done in a way that each single category is symbolically awarded suitable number of ship propellers (screws): tourist yachts / craft for tourist cruises of the first category - three ship propellers, tourist yachts / craft for tourist cruises of the second category – two ship propellers, tourist yachts / craft for tourist cruises of the third category - one ship propeller.

3.2.3. Comparative analysis

From the aspect of safety of nautical tourism vessels, the *Maritime Code and the Ordinance on Boats and Yachts* are the most important regulations in Croatia. Their terminology should be the norm of all the other regulations and official documents. However, after examining the report of the Central Bureau of Statistics, it can be seen that the terminology used does not comply with these regulations. That is, the phrase *other vessels* includes boats of up to 3 meters in length or more, or of less than 3 meters if they have engines. Maritime legislation does not recognise the term *smaller boat* (cro. čamac), but instead, uses the term *boat* (cro. brodica) which is limited to 2.5 meters in length. By analyzing the data from the report of the Central Bureau of Statistics, it is not possible to obtain the actual facts on the types of nautical tourism vessels, and that, somehow causes the terminological ambiguity. We, therefore, believe that it is necessary to align the terminology of the Central Bureau of Statistics with the definitions of *the Maritime Code* and *the Ordinance on Boats and Yachts*.

By analyzing the definitions of vessels in nautical tourism used in various regulations in Montenegro, we can see that there is even greater inconsistency in determining the terms, and overlapping of the definitions of certain types of vessels. In *the Law on Yachts*, for example, there is the definition of *smaller foreign boat* as a vessel that has a foreign flag, and in fact, the very term of the *smaller boat* has not been defined. On the other hand, the same *Law* defines the terms *yacht* and *foreign yacht*. Thus, it can be interpreted that a smaller boat is any vessel that is not a yacht, which is not the case in any way.

Therefore, *in the Law on Yachts* it is necessary to define the general term *smaller boat* before defining the term *smaller foreign boat*. *The Law on Safety of Maritime Navigation* is less ambiguous as it includes the definitions of the terms: *ship, boat, smaller boat and yacht*. According to it, *boat* is a vessel intended for navigation, 7-12 meters in length, and a gross tonnage of less than 15 tons, with power of less than 75 kW. *Smaller boat* is a vessel intended for navigation at sea, which is neither a boat nor a yacht, whose length is over 2.5 meters, or engine power greater than 5 kW, while *yacht* is a vessel more than 7 meters in length, intended for sport, leisure and recreation. However, we believe that the term *boat* is not sufficiently clear and to some extent it overlaps with the definitions of *smaller boat* and *yacht*. It is well known that in technical terminology, the terms *boat* and *smaller boat* are used as synonyms, while according to *the Safety of Maritime Navigation* it seems that *boat* is a subtype of *yacht*, which certainly was not what the legislator had in mind. The definition of a *boat* is unclear and unnecessary, consequently, we believe that it should be removed from the legislation. Furthermore, comparing *the Law on Safety of Maritime Navigation* to *the Ordinance on Smaller Boats*, which defines *smaller maritime boat* as a vessel designed to sail, with length of less than 12 meters, and the registration capacity of less than 15 gross tons, it is obvious that there are different definitions for the same term in different regulations.

It should also be noted that the Croatian and Montenegrin regulations differently define *yacht* as a vessel for sport and leisure. According to Croatian law a yacht is over 12 meters in length and it is registered for the stay and transport of not more than 12 persons, while according to the Montenegrin regulations *yacht* is at least 7 meters in length, without limitation in the number of persons.

After analyzing Croatian and Montenegrin regulations it can be concluded that in the definitions of vessels the only properly defined term is *ship* because this type of waterborne craft is subject to international regulations and standards. The definitions of vessels used in nautical tourism significantly differ both within the national legislation and between the two countries. This should not be the case in any way given that both countries have the same factors that influence the development of nautical tourism, and a similar profile of boaters-tourists staying on the vessels of nautical tourism. One gets the impression that it favours particular interest groups, and that there is no long-term vision of the legal regulation of such significant part of the maritime and tourist activities.

4. Maritime accidents and safety of navigation in the nautical ports aquatorium

4.1. Concept and types of maritime accidents

Since its beginnings, sailing has been accompanied by various risks that have endangered the safety of persons and property. Technical and technological advances in the construction and operation of vessels have reduced, but not eliminated the risk. This has also been contributed by an increasing number of different ships and craft engaged in international and national voyages. A maritime accident or incident is an event or set of events of the same origin that causes loss or damage to the ship, yacht, boat, cargo, other property at sea, which also causes human suffering (death or bodily injury of crew, passengers or third parties). The event that causes the maritime accident should be of exceptional nature - regular losses or expenses that accompany transportation and maritime activities are not maritime accidents. Maritime accidents can be caused by hazards of the sea (*force majeure* or unexpected occurrence) and actions of people who may be members of the ship's crew, or a third party. (Pavić, 2006)

In Croatia and Montenegro, national centres and sub-centres for coordination of search and rescue operations at sea provide assistance in the event of maritime accidents. Providing assistance in the event of maritime accident depends on the type and nature of the accident itself and the characteristics of the vessel, and the circumstances in which a harmful event occurred. Therefore, in continuation of this paper the basic features of maritime accidents shall be presented, emphasising those that are common to the vessels in nautical tourism.

The collision of vessels (yachts, boats) is material impact of two or more vessels, which results in damage to at least one vessel, property or the people on board. The collision of vessels (yachts, boats) usually occurs in narrow navigable waters (straits), or where there is heavy traffic (during entry or departure). Due to their often different sizes and speed, the nautical tourism vessels frequently suffer injuries or death of a person in the event of collision. (Luković et al., 2015)
The impact is a material collision of vessels with fixed sea or land structures; the term *impact* means that there is a powerful contact of a vessel with a structure that is not considered a craft. Most frequently, vessels suffer damage during the impact.
Grounding is a marine accident when the boat with its entire keel or just a part of it touches the bottom. Grounding usually occurs due to the error of the person that is navigating a vessel, or in the event of propulsion system failures due to the influence of wind and waves. The consequence may be severe damage to the hull due to its exposure to multiple impacts at the bottom.
The penetration of water (flooding) is any unintentional ingress of water in quantities threatening the seaworthiness of the vessel. The penetration usually occurs due to external forces (waves, mechanical impact force) or due to a malfunction of equipment parts.
Sinking of the vessel is an accident in which there is a permanent or temporary loss of seaworthiness and the loss of floating ability by its being fully or partially submerged in the sea.
The fire is uncontrolled burning mostly caused by maltreatment of vessel's equipment. The main characteristic of fire is its rapid spreading which leaves very little time for its prevention. Breaking out of a large fire regularly results in complete destruction of the vessel, and its sinking if it is far from the shore or in shallow waters. (Luković et al., 2015)
Person overboard is usually a result of negligence or falling from the ship. In case of bad weather, the person in water is at great risk, especially in case of low temperatures of the sea when the survival time is significantly reduced. (Luković et al., 2015)
Pollution of the marine environment can be caused by any vessel including the vessels of nautical tourism. Certainly there is a greater danger of ships, especially tankers, due to the type and quantity of the cargo transported. However, smaller vessels also pose a threat to the marine environment primarily by fuel leakage.
It should be noted that many accidents occur due to the very low level of expertise of persons who navigate the vessels of nautical tourism.

4.2. Safety in ports and convenience of nautical tourism ports

Sailing of the vessels of nautical tourism takes place for the most part near the indented coast, with numerous islands, islets, reefs, bays, creeks and sea straits. On the one hand, sailing in such areas is very exciting and provides direct contact with the beauty of nature, and on the other hand, there are many safe havens in case of adverse weather conditions.
From the standpoint of weather conditions affecting the safety of navigation, the sailing in the Adriatic Sea on the vessels of nautical tourism can be divided into two distinct areas: sailing in the open seas and in the coastal navigation area, relatively close to the ports of nautical tourism. These two areas are different in terms of effects of weather conditions on navigation and safety procedures in case of threats to the safety of navigation.
Depending on the size of the vessel, winds, waves and other weather factors have different effects on navigation, or altering the course and speed of the vessel. At the same time, the Adriatic sea is relatively safe for nautical vessels in the summer months, while it is quite the opposite in winter when it can get very unpleasant, especially for smaller vessels. The consequence of the above are two fundamentally different traffic periods: the summer months, during which a large number of vessels sail between different destination ports, and the winter period, during which the traffic of small boats is almost negligible and therefore, adverse weather conditions have a relatively small impact on the overall safety of navigation. (Luković et al., 2015)
From the standpoint of safety of navigation, nautical tourism ports provide a sufficient level of safety of vessels at berth, both during the summer when there are frequent arrivals and departures, as well as during the winter, at a time when most of the vessels have no permanent crew engaged.
The marina offers the highest level of security for vessels at berth. It should be noted that regarding the safety, the marinas built in the area that is not naturally protected from the effects of the sea may have parts in which there may be a higher uncertainty of mooring, under particular circumstances. This refers primarily to the marinas where the impact of waves has been reduced after the construction of breakwaters and where in case of full occupancy of the marina and in the event of a major storm, boats moored near the entrance may be exposed to intensive motions in the waves producing the relevant consequences. (Luković et al., 2015)
Mooring (berth) provides a different level of security to the vessels at berth. If it is placed deep in the protected bays or within the protected part of the public or other ports, the security guaranteed to the vessels is very high, especially if vessels of appropriate size are moored, and if adequate mooring equipment is used. In case of such mooring, it is possible to have a safe stay throughout the year including the winter storage of a vessel at its berth. Of course, there are opposite examples of mooring that are fully exposed to the bad weather conditions. In such cases, the mooring is possible only during the summer period.
Anchorage generally provides a satisfactory level of safety during the summer period. During the rest of the year, when the probability of adverse weather conditions is significantly higher, the safety of boats at anchor is often questionable.

In this respect the use of anchors, as a rule, is limited to the summer months.
Traffic in the areas near the ports of nautical tourism is affected by the characteristics of each port. However, the maritime traffic in the vicinity of the ports of nautical tourism and other parts of internal waters marks the annual turnover which is most pronounced during the summer period, weekly traffic which is most intense at the end of the week (when there are crew changes on the rented boats), and daily traffic which is significantly increased during the morning hours when the boats leave the port, or in the evening when a significant number of vessels return to spend the night in the port. (Luković et al., 2015)

4.3. Maritime accidents with regard to the type of nautical tourism vessels

Properties of certain vessels are crucial to the safety of navigation and protection of the marine environment. In nautical tourism there are numerous vessels of different characteristics and purpose, thus, the threats they are exposed to are very diverse.
From the standpoint of the threats boats and yachts are exposed to, it is possible to use the classification of these vessels by size, or the major propulsion they use, as well as by the speed they can develop. The propulsion of vessels can directly affect the shape of the hull, and consequently the conduct of these vessels in navigation. As a result, there is a distinction between the motor boats, yachts and sailboats. The speed that the boat develops when moving through the water is often crucial for the safety of navigation. In this regard we should distinguish boats and fast boats.
Regular boat speed is low, rarely over 7-8 knots. The boats that are smaller in length are usually owned by the local population, and are used for short stays at sea, at short distances from the coast, and in good weather conditions. They are moored in marinas, while some of them are anchored in naturally protected bays. It should be noted that the way of mooring and arrangement of boats in (sports) ports usually do not fully meet the standards of safety for berthing and stay of the vessel as a result of insufficient number of available berths, especially in the summer months. These boats are subject to accidents (collision, crash, sinking, etc.) at the place of berth, when manoeuvring in harbours or when sailing. Usually, the accidents that happen during the manoeuvring do not lead to the loss of the vessel. There are often incidents of boats hitting shore or other vessels at berth and the mooring ropes getting entangled in the ship's screw, usually due to manoeuvring errors. Accidents happen due to insufficient space for berthing in ports, particularly with regard to the width of the fairway and the space needed for manoeuvring, or because of too many boats in the harbour. The most common navigation accidents occur due to the failure of propulsion engine, stranding as a result of bad weather and a collision. Collisions may occur at low speeds (which rarely happens in practice), and they usually do not cause greater damage to the boat. In a collision of boats, of which at least one is moving at a higher speed, more serious damage may be caused, personal injuries or even a loss of life. (Luković et al., 2015)
Fast boats (speedboats) may be constructed of reinforced fibreglass, and they are often made of rubber (inflatable boats). Their weight is small, which makes them liable to the influence of wind forces. Their draft is also small allowing an easy access to the undeveloped coasts. At the same time, because they usually do not have a keel, it is very difficult for them to maintain the course. Their usual speed is 12-35 knots. They are often used for one-day sailing trips in good weather conditions. Most of these boats do not have permanent berth in harbours or marinas, and their owners transport them by roads or in winter, leave them in dry marinas that take care of their storage. In the period of their intensive use they are moored at the places for rent, or improvised berths set up by boat owners, and most often are not sufficiently sheltered. Only a small number of these boats are engaged on a berth contract with marinas. Accidents of fast boats equally occur at the place of mooring when manoeuvring in harbours and in navigation. The accidents during the manoeuvring of these boats do not differ from the accidents which involve similar boats of lower speed. Because they often use petrol engines, there is an increased risk of fire on these boats. In navigation, accidents occur mainly due to negligence, but also because of speeding. Events of a collision or grounding at higher speed result in considerable material damage, increased risk of injury and death of crew members and passengers. The accidents of fast boats often take place in the area less than 300 meters away from the coast and primarily due to non-compliance with the rule of sailing at reduced speeds. In this way, they pose a great threat to swimmers.
Yachts of up to 15 meters in length are fast vessels, usually constructed of reinforced fibreglass, of small weight and subject to greater influence of wind forces. The ratio of their surface and submerged parts is relatively large. These boats have very powerful engines that at low rpm develop considerable speed from 15 to 35 knots. Due to these characteristics, the skipper needs sufficient space, and he is required to possess considerable skills in controlling the yacht. Manoeuvring can become particularly difficult if the wind increases the speed. These yachts are commonly used for longer cruising excursions. During the year, a significant number of these vessels use permanent berths in the marinas. As they often change the ports for overnight stay, they are considered as transit vessels in the ports where they berth. With regard to the safety of navigation, everything that has been said of the fast boats applies to yachts of up to 15 meters in length, only they require significantly greater space for manoeuvring and mooring. These vessels rarely have accidents at sea and it is primarily because of their size that they rarely approach the coast, their equipment is more sophisticated, and they have better resistance to the impact of adverse weather conditions. Fires and explosions in this group of vessels are much rarer because they mainly use diesel engines. During the mooring these yachts often hit the shore, collide with other vessels or get the mooring ropes entangled in the propeller due to insufficient knowledge and skills of the persons who run them and external conditions.
Yachts of 15 to 30 meters and over are called *large yachts*. Although, due to their purpose, technological features and sophisticated equipment they seem similar to the previously described group of yachts, they are, in fact, much more

similar to ships. They mostly have a propeller or, sometimes, jet propulsion. The speeds developed by these yachts range from about 15 to 35 knots. They are usually used for longer cruises, and given their size they can easily navigate in adverse weather conditions. These vessels are often anchored outside the ports, and passengers are transported to shore by launches. Because of their length (especially yachts over 25 meters) they can only berth in larger marinas i.e. the larger ports open to public transport. The number of accidents of large yachts is much smaller in relation to the accidents of all other types of nautical tourism vessels. This is due to considerably better equipment, much better maintenance, and for the most part, the fact that they are run by qualified and experienced crew, and not by their owners or users. The characteristics of the accidents that occur are not significantly different from the characteristics of smaller ship accidents.
Regarding the threats to the safety of navigation of *sailing boat*s, it is most convenient to distinguish the sailing boats of up to 15 meters in length, and those over 15 meters. Sailing of boats of up to 15 meters is very similar to the sailing of boats and motor yachts of the same length. A significant difference occurs primarily in the part referring to the manoeuvring characteristics during the navigation in unfavourable weather conditions.
Sailing boats are very stable vessels, with large draft and lower freeboard they can maintain their course very well. These vessels develop the speed of about 10 knots by their propulsion units. Above described sailing boats are subject to grounding and less often to collision accidents due to quite low speed of navigation. The largest number of incidents of these vessels is caused by incompetence or inexperience of their skippers.
Larger sailing boats (more than 15 meters in length), or sailboats are generally technologically highly sophisticated craft. They can reach a length of more than one hundred meters, most often them are used as racing boats for the most demanding competitors, or as tourist boats intended for the most demanding clientele. In both cases, they are constructed of very expensive materials and with the latest state-of-the-art technology. As the handling of these vessels requires a high level of expertise, skills and experience, the same as large yachts, they are also run by qualified and experienced crew and therefore they are rarely involved in accidents. It is not common for these vessels to sail near the coast. The number, characteristics and frequency of their accidents approximately correspond to the number of accidents in passenger ships in international voyages.

5. Conclusion

Applicable Croatian and Montenegrin legal regulations have roots in former Yugoslavia regulations and therefore there is a lot of similarity in the current legal framework of both countries. Because of this and due to the international character of maritime affairs and tourism, most maritime law institutes governing nautical tourism are very similar. However, there are certain differences that have arisen due to the adjustment of particular institutes with national interests. This means the regulation of the legal status of vessels and nautical tourism ports, but not the provisions on maritime safety.
Although the vessels in nautical tourism are not subject to the provisions of international conventions, and are subject only to national legislation, both countries seek to meet high standards of navigation safety of yachts and boats, that being a prerequisite for the sustainable development of nautical tourism.
By analyzing the legal provisions applicable to the facilities of nautical tourism one can observe a large number of different laws and regulations that are not always mutually consistent neither in the legislation of individual countries nor in comparative law.
Inconsistency in definitions and types of nautical tourism facilities is also enhanced by the fact that the regulations in the domain of nautical tourism in Croatia and Montenegro are adopted within the framework of two different ministries – Maritime Affairs and Tourism. For the Ministry of Maritime Affairs the most important is the safety aspect of vessels navigating in the internal waters and territorial sea, while the Ministry of Tourism cares more for the tourist offer in nautical tourism as demonstrated by the categorization of specific regulations.
The analysis of the existing provisions shows that there are too many regulations that govern the activities of nautical tourism, hence the inconsistency, excessive regulation and legal gaps in the existing legislation. It all has certainly been affected by different political and economic interests that influence the adoption of various regulations. An example of this is Croatia which has been waiting for years for the adoption of a new and better quality A*ct on Maritime Domain and Seaports*. Because of different interests and conflicting opinions a series of attempts to adopt a new legal text have failed. Quality regulation of maritime domain is one of the preconditions for the efficient development of nautical tourism ports.
From all of this we can conclude that a thorough review of existing legislation in Croatia and Montenegro is essential, thus, the proposal for the set up of working groups in each country made up of experts who are engaged in the specific activities of nautical tourism in order to comprehensively and clearly regulate this important economic activity.

Acknowledgements

This paper is a result of the authors' research under the research project of the Adriatic Institute of the Croatian Academy of Sciences and Arts, funded by the Croatian Science Foundation, titled Developing a Modern Legal and Insurance Regime for Croatian Marinas – Enhancing Competitiveness, Safety, Security and Marine Environmental Standards (DELICROMAR, UIP-11-2013 no. 3061, project period: 1st March 2016 – 28th February 2019). More information about the project is available at www.delicromar.hazu.hr

References

Grabovac, I. 2005. *Suvremeno hrvatsko pomorsko pravo i Pomorski zakonik* (*Modern Croatian Maritime Law and Maritime Code*), Književni krug, Split

Grabovac, I.; Petrinović, R. 2006. *Pomorsko pravo* (*Maritime Law*), Split

Luković, T.; Bilić, M. 2007. Luke nautičkog turizma u Hrvatskoj i strategija lokalnog razvitka (*The Ports of Nautical Tourism in Croatia and Strategy of Local Development*), *Naše more*, 54(3-4), Dubrovnik

Luković, T. et al. 2015. *Nautički turizam Hrvatske* (*Croatian Nautical Tourism*), Redak, Split

Milošević Pujo, B.; Petrinović, R. 2008. *Pomorsko pravo za jahte i brodice* (*Maritime Law for Yachts and Boats*), Split

Odluka o određivanju luka prema značaju (*The Decision* on *Determination* of *Ports according* to *Significance*), Official gazette of the Republic of Montenegro Nos 20/11, 41/12 and 14/14.

Pavić, D. 2006. *Pomorsko imovinsko pravo* (*Maritime Property Law*), Književni krug, Split

Pomorski zakonik Republike Hrvatske (*Maritime Code of the Republic of Croatia*), Official gazette of the Republic of Croatia Nos. 181/04, 76/07, 146/08, 61/11, 56/13 and 26/15.

Pravilnik o brodicama i jahtama (*the Ordinance on Boats and Yachts*), Official gazette of the Republic of Croatia Nos. 27/05, 57/06, 80/07, 3/08, 18/09, 56/10, 97/12, 137/13 and 18/16.

Pravilnik o razvrstavanju i kategorizaciji luka nautičkog turizma (*the Ordinance on the Classification and Categorization of Nautical Tourism*), Official gazette of the Republic of Croatia Nos. 72/08.

Pravilnik o uvjetima koje moraju zadovoljiti plovni objekti, te fizička ili pravna osoba koja obavlja djelatnost iznajmljivanja plovila (*the Ordinance on the Conditions to be met by Vessels, and Natural or Legal Person Performing the Activity of Leasing Vessels*), Official gazette of the Republic of Croatia Nos. 41/05 and 62/09.

Pravilnik o uvjetima za obavljanje djelatnosti iznajmljivanja plovila sa ili bez posade i pružanje usluge smještaja gostiju na plovilu (*the Regulation on Conditions for Leasing Vessels with or without Crew and Offering Accommodation Service on board Vessels*), Official gazette of the Republic of Croatia Nos. 99/13.

Pravilnik o vrstama i kategorijama plovnih objekata nautičkog turizma (*the Ordinance on the Types and Categories of Vessels of Nautical Tourism*), Official gazette of the Republic of Croatia Nos. 69/08, 83/09 i 49/15.

Pravilnik o vrstama objekata nautičkog turizma, minimalno tehničkim uslovima i njihovoj kategorizaciji (*the Rulebook on Types of Nautical Tourism Facilities, Minimal Technical Conditions and their Categorization*), Official gazette of the Republic of Montenegro Nos 9/03.

Strategija razvoja nautičkog turizma Republike Hrvatske (*Development Strategy of Croatian Nautical Tourism*), 2009.-2019.

Šamanović, J. 2002. *Nautički turizam i management marina* (*Nautical Tourism and Marina Management*), Visoka pomorska škola u Splitu, Split, Hrvatska.

Uredba o čamcima (*Regulation on smaller boats*), Official gazette of the Republic of Montenegro Nos 51/04 and 44/09.

Uredba o razvrstaju luka otvorenih za javni promet i luka posebne namjene (*the Regulation on the Classification of Ports Open for Public Transport and Ports for Special Use*), Official gazette of the Republic of Croatia Nos. 97/13.

Uredba o uslovima koje moraju da ispunjavaju luke razvrstane prema vrsti pomorskog saobraćaja i namjeni (*Regulation on Conditions* that must be *met by Ports Classified* according to the *type of Maritime Traffic* and *Purpose*), Official gazette of the Republic of Montenegro Nos 20/11.

Uredba o uvjetima kojima moraju udovoljavati luke (*the Decree on Conditions that Ports Must Meet*), Official gazette of the Republic of Croatia Nos. 110/04.

Uredba o uvjetima za dolazak i boravak stranih jahti i brodica namijenjenih športu i razonodi u unutarnjim morskim vodama i teritorijalnom moru Republike Hrvatske (*the Regulation on Conditions for the Arrival and Stay of Foreign Yachts and Boats Intended for Sport and Leisure in the Internal waters and Territorial Sea of the Republic of Croatia*), Official gazette of the Republic of Croatia Nos. 97/13.

Zakon o jahtama (*the Law on Yachts*), Official gazette of the Republic of Montenegro Nos. 46/07, 73/10, 40/11 and 42/15.

Zakon o lukama (*Port Law*), Official gazette of the Republic of Montenegro Nos 51/08, 40/11 and 27/13.

Zakon o moru (*The Law of the Sea*), Official gazette of the Republic of Montenegro Nos 17/07 and 6/08.

Zakon o morskom dobru (*The Law on Maritime Domain*), Official gazette of the Republic of Montenegro Nos 14/92.

Zakon o pomorskom dobru i morskim lukama (*the Maritime Domain and Seaports Act*), Official gazette of the Republic of Croatia Nos 158/03, 141/06, 38/09, 123/11 and 56/16.

Zakon o pružanju usluga u turizmu (*Act on the Provision of Tourism Services*), Official gazette of the Republic of Croatia Nos 68/07, 88/10, 30/14, 89/14 and 152/14.

Zakon o sigurnosti pomorske plovidbe (*the Law on Safety of Maritime Navigation*), Official gazette of the Republic of Montenegro Nos 62/13, 6/14 and 47/15.

Zakon o zaštiti mora od zagađivanja sa plovnih objekata (*The Law for the Prevention of Pollution from Ships*), Official gazette of the Republic of Montenegro Nos 20/11, 26/11 and 27/14.

A VERIFICATION OF A REMOTE MONITORING OF RESULTS OF BALLAST WATER MANAGEMENT SYSTEM

Goran Bakalar[1], Myriam Beatriz Baggini[2]
[1,2] Bonum Mare Consulting LLC, 148 Young Ave, Cocoa Beach, 32932, FL, USA

Abstract: Remote monitoring of BW (ballast water), after being treated by any BWTS (Ballast Water Treatment System) on board ships is the only autonomous detection system for this purpose suggested at this time. The experience from ships indicated operational problems with the treatment of ballast water on board the ships. Another problem, confirmed by scientists, is re-growth of microorganisms after the treatment. Automated monitoring of treated BW on ships is a solution. It was specified, described and mathematically proved and verified in this article. Sophisticated part of this system, flow cytometer, needs some specific conditions for the operation. Important pressure reduction is an obligation and was explained and suggested the procedure and possibility of implementation. Remotely operated from land, this system improves traffic environment**.** Result of this study is a verification that brings up more trust in this automated system that verifies contents of ships' ballast water before a ship enters a port.

Keywords: remote operations, monitoring devices, ballast water management, flow cytometer.

1. Introduction

After and during the cargo loading from commercial ships, water is taken to ensure ship's strength and stability. This water is called ballast water. Non-native marine species arrive in ports via ballast water which is being discharged while the cargo is loaded. The BWMC (*Ballast Water Management Convention*) 2004 protects the sea environment through regulations regarding ballast water treatment (Bakalar, 2011). Therefore, most of ships will have to treat ballast water once the Convention comes into force. Regulations and standards established in D-2 regulation (Globallast, 2016) of the Convention, by the IMO (*International Maritime Organization*), require treatment limits to be met independently and calls for vessels to carry out monitoring themselves (Albert et al., 2013). Many successful, type approved technologies have been suggested for ballast water treatment (EPA, 2011; Lloyd's, 2014), such as disinfection with chlorine (Simpson, 2011), injecting chemicals (La Carbona et al., 2010), adding biocides to ballast water for the neutralisation of harmful microorganisms, sterilisation with ozone (Perins et al., 2006), filtration with UV (ultraviolet) light (Suherland et al., 2003), electro-ionization (Aliotta et al., 2001), exposure to cavitation (Cvetković et al., 2015; Cvetković et al., 2016), and magnetic separation (Ren et al.,2016). Some of the suggested type approved systems are more effective in neutralizing microorganisms such as bacteria and zooplankton and other systems cannot treat them so well. No system can inactivate all microorganisms in ballast water. Some states require implementation of sampling of treated ballast water before they approve and sign the Convention. The solution verified by authors in this article is a monitoring system that could be implemented in the maritime industry. A shipping company would make an additional confirmation of high quality of their operations if they implement this automated remote autonomous system in their fleet.

2. Materials and methods

Certain systems for detection of ballast water were suggested by scientists (Bakalar and Baggini, 2016; Bakalar and Baggini, 2016a; Bakalar and Tomas, 2011). It can be indication monitoring or compliance monitoring within required treatment limits. Indication means that the detection result proves that a treatment was performed. Compliance monitoring results show the exact amount of certain microorganism in a sample of ballast water. Some of the indication monitoring technologies work with enzimes and total energy detected in a sample. Another technologies, like Pulse-Amplitude-Modulation (PAM) fluorometry, measure fluorometric character of a particle (Schreiber,2004). The amount of remaining energy or enzimes is a proof of whether a ballast was treated at all or not. Flow cytometer is a detection sensor device of compliance monitoring and needs an operator just to calibrate it using a computer after each completed detection (Bakalar, 2014). The time of DNA detection in laboratories has been shortened from days in the past down to three hours (Asai et al., 2003). Flow cytometer is capable to scan 10,000 different particles per second (Bakalar, 2013). It detects all different DNA of the smallest microorganisms. That is needed because the smallest microorganisms were not included in BWMC 2004 (van Der Star et al., 2011). Also, regrowth of treated microorganisms (Grob et al., 2016; Liebich et al., 2012; Macintyre et al., 2016) would be cotrolled in this way. It is important that this detection sensor is capable to be operated autonomously and remotely. All other detection methods and their devices need significant operational assistance by humans (Bakalar and Tomas, 2016).

2.1. Automated autonomous remote system of detection of ballast water contents

Flow cytometer has been suggested by certain scientists to monitor chemical pollution from the ships in coastal areas (Bakalar et al., 2011). In Fig. 1 is a drawing of a system that has been suggested for early discovery of unwanted ballast water contents, using fixed flow cytometer, filtration of scanned data and communication sub-system that automatically transfers data from the ship to a land office. This system includes sub-systems and remote operation from the shore side

[1] Corresponding author: Goran.Bakalar@xnet.hr

office, autonomous from ship's crew. Flow cytometer could be fixed onto the ballast water pipeline system at the location that is available for detection of all ballast water tanks on board ship.

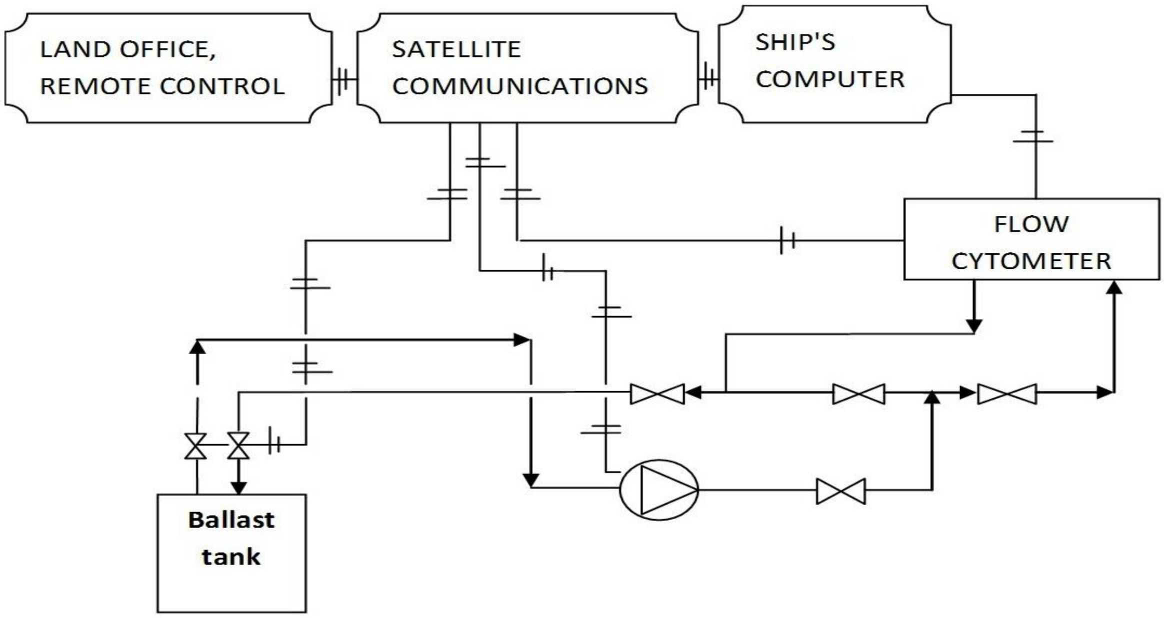


Fig. 1.
Remote detection system, using flow cytometer and satellite communication
Source: Modified from (Bakalar, 2013)

This system has been applied for a patent and it was presented in scientific and IMO conferences and published in scientific journals (Bakalar, 2015; Bakalar, 2016). The main purpose of this detection system is to timely, automatically and autonomously from ships' crew members, sample treated ballast water and send the information of ballast water status on a ship, to the land office. This system includes sub-systems and remote operation from the shore side office, autonomous from ship's crew. It is a remotely operated ship's ballast water detection system from land-based office. Remote communication of sensor data in ballast water treatment systems was researched (Kim et al., 2014) and trend analysis and diagnosis for BWTS remote monitoring of proper dosage in neutralization unit was analyzed (Choi et al., 2014). A fixed flow cytometer on the ship is remotely run that analyses treated ballast water with recirculation (Bakalar, 2012). The data of the flow cytometry scans are transmitted by an INMARSAT satellite communication system. Flow cytometer detects data after the dosing pump (inside the flow cytometer unit) takes on and off the samples. The software filters detected data after that. Software is programmed to filter and archive just needed information (related to D-2 regulation of BWMC 2004) (Bakalar, 2013). INMARSAT communication system transfers data on time, tunneling privacy with firewall network protection. The operator in land office performs remote control of ballast water. Remote operation is already in use in maritime industry for remote maintenance and supervision of some other processes on ships (Bakalar, 2012a). The control of contents of ballast water is remotely operated by the automatic detection of ship’s ballast water via satellite communication from land. It commences before the ship enters the port in which cargo will be loaded, in a manner agreed upon by the staff from the office located on land and the staff that is located on ship. Remote operation in this system includes opening valves of ballast water tanks, operation of ballast pump and operation of flow cytometer detection. Once the detection with negative results is completed, the operator in land office grants permit for the ship to enter port with confirmed clean ballast. If the result of detection was positive, the operator will not grant permit to ship to enter the port since flow cytometer detected discrepancy to D-2 regulation of the Convention. In Fig. 2. the pipelines flow cytometer unit are adjusted to reduce the pressure that has been driven from main ballast water pipeline into the flow cytometer detection unit.

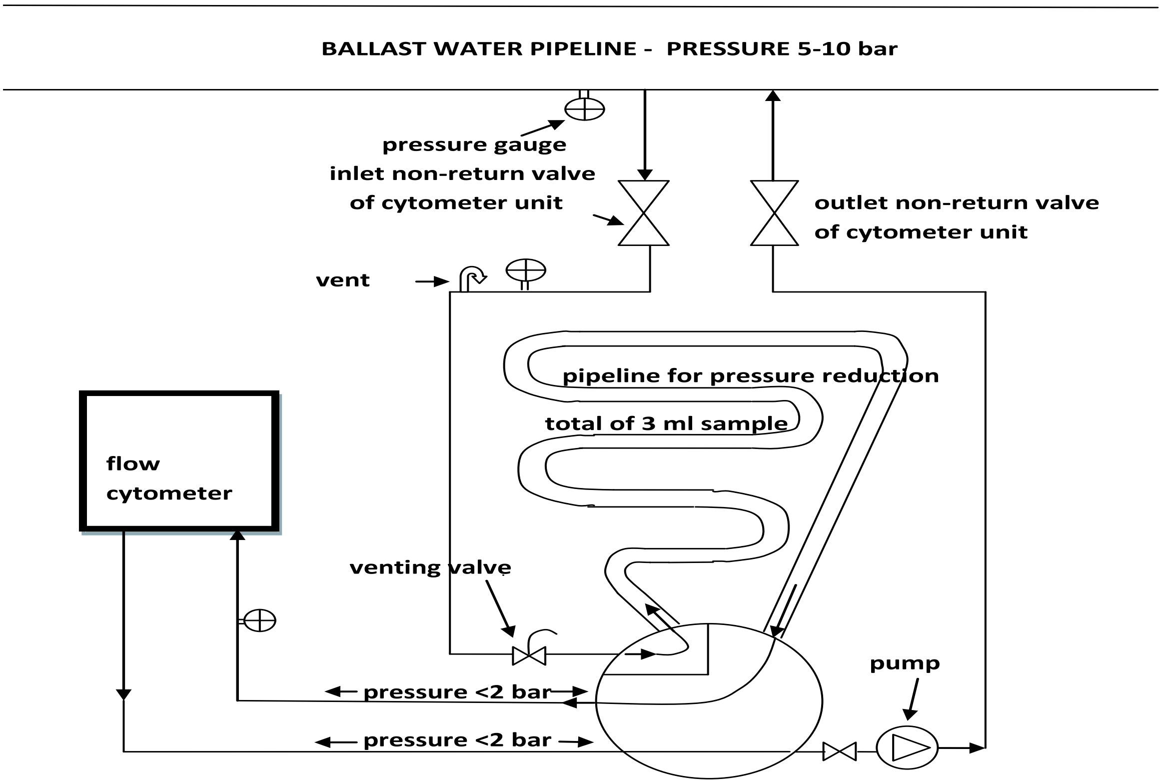


Fig. 2.
Flow cytometer unit

One of the most important conditions for flow cytometer, that needs to be verified, is the flow pressure of sampling water. The pressure cannot be higher than 2 bars, otherwise a flow cytometer would not be in proper operation (Bakalar, 2015). Verification of possibility of pressure reduction, in accordance with the drawing and suggestion in Fig. 2, is in following section.

3. A verification of the automated autonomous remote system of detection of ballast water contents

In following calculation is confirmed a pressure loss in flow cytometer unit. The pressure has to be lowered below 2 bars. That is a basic working condition for flow cytometer operation. As an example is taken a ship long L= 250 m, with width B= 50 m, hight of bulhead deck D= 25.

Inner diameter d_u is defined as follows:

$$d_u = 1.68\sqrt{L\ x\ (B+D)}\ + 25\ mm \tag{1}$$

and calculated diameter of ballast water pipeline is:

$$d_u = \sqrt{250x\ (50+25)}\ + 25\ mm = \sqrt{18750} + 25 \text{ mm} = 161.93 \text{ mm} \tag{2}$$

Ballast water flow through the pipeline is, in this case, stationary because the water fills whole inner diameter in the pipeline pressurised and driven by ballast pump maximum capacity of 2000 $\frac{m^3}{h}$ ili 0.555 $\frac{m^3}{s}$.

Pressure drop in a ballast water pipeline is in depend to inner resistance. Inner resistance is in depend of kind of flow, temperature and speed, and, the most important for this study, numerous kinds os narrowings in a pipelines system. The first pressure loss can be on T-connection, as shown on Fig. 2. That is the first connection of flow cytometer unit and ship's ballast water pipeline system. Next pressure reduction point is at inlet non-return valve of cytometer unit. Loss factor used for pressure loss in T-connection is ξ =0.11, added to pressure loss because of narrowing the space in the pipe of (calculated in 2nd equiation) 161.93 mm into 120 mm in relation

$\xi = \frac{120}{162}$. Pressure drop ξ of the narrowing at the valve is in relation to human operator and his decision or it was automaticaly ordered. Automatic valve can be narrowed of 30% of inner diameter in relation $\xi = \frac{80}{120}$ and pressure could be lowered down to required pressure by pump capacity that also can be regulated automaticaly or by operators' decision. Important factor is ballast water velocity:

$$\text{v = ballast water flow velocity } \frac{m^3}{s} \tag{3}$$

ξ of T-connection and narrowing of inner diameter of flow cytometer pipeline is:

$$\Delta p = \xi \text{ x } \frac{p\ x\ v^2}{2} = 0.81 \text{ x } \frac{5\ x\ (0.555\ \frac{m^3}{s})^2}{2} = 0.62375 \text{ bar} \tag{4}$$

ξ at the narrow of inner diameter caused by 30% reduced valve opening is:

$$\Delta p = \xi \text{ x } \frac{p\ x\ v^2}{2} = 0.66 \text{ x } \frac{4.37625\ x\ (0.555\ \frac{m^3}{s})^2}{2} = 0.674 \text{ bar za } \xi \tag{5}$$

The next step is pressure reduction by bending pipe of od *90°:* gained loss factor ξ = 1.2 and pressure reduction is:

$$\Delta p = \xi \text{ x } \frac{p\ x\ v^2}{2} = 1.2 \text{ x } \frac{3.70225\ x\ (0.555\ \frac{m^3}{s})^2}{2} = 0.68423 \text{ bar} \tag{6}$$

The last significant pressure loss is obtained by six times bended pipe, as agreed while the first author of this article was in visit in CytoBuoy institute, ξ =0,16:

$$\Delta p = \xi \text{ x } \frac{p\ x\ v^2}{2} = 6 \text{ x } 0.5 \text{ x } \frac{3.01802\ x\ (0.555\ \frac{m^3}{s})^2}{2} = 1.39444 \text{ bar} \tag{7}$$

Total pressure reduction till dosing pump in cytometer sampling unit is: ξ =3.37642

The measured pressure in main ship's ballast pipeline, at the beginning of this calculation, was 5 bar. The pressure was reduced down to 1.62358 bar and required pressure < 2 bar was verified. That pressure is good enough for proper flow cytometer function.

Malfunction index in this system is the relation between malfunctioning components and proper components:

$$\lambda = \frac{1}{P_c} \frac{d\,P_f}{\Delta t} \tag{8}$$

where P_c is the number of components which remained in proper functionality after a specified time, and P_f is the number of components which remained malfunctioning after the specified time of function.

Reliability of sophisticated part of the system is:

$$R\ (t) = P_c\ (t) = e^{-\lambda t} \tag{9}$$

which means that reliability in the function of time depends on probability of proper function and failures in specified time.

4. Discussion

Redundancy is the characteristic of computing system quality that ensures failure avoidance when a part of the system fails. This is most commonly ensured with additional spare software, by reliability of the two systems working parallely with achieved redundancy and a known malfunction index for these types of devices in determined on board the ships conditions.

It has been assumed in previous researches that the computing part of the subsystem in the system with two parallel subsystems, one of which is redundant, will be regularly maintained by operator and by self-diagnosing automatic function errors removal (Bakalar, 2016; Bakalar and Tomas, 2016). In this way, the possibility of malfunction of some ballast water treatment systems on board the ships is lowered. Malfunction index or failure for maintenance which is impossible to be diagnosed and automatically removed for this type of device of reliability for 1000 hours of work, Reliability of this type of sophisticated systems on ships was calculated in previous certain research and it was *R(t)* = 0.704688 (Bakalar, 2013). Total reliability of the whole computing subsystem as a part of some ballast water treatment systems on board the ships which consists of the two units of which one is software redundant is *R(u)* = 0.93097 (Bakalar, 2013). After the analysis of the reliability of the computing system, which is a subsystem of certain ballast water treatment systems on board the ships, the trust in this subsystem has been proven. The computing subsystem reliability with eventual use of redundant software is 0.931 or 93.1%. That reliability also has to be proven in the operations on board the ships. There were reported experienced operational problems with BWTS on ships (Bakalar, 2016a) and it was suggested action similar to suggestion in certain previous research (Bakalar, 2011a). System reliability of mechanical parts and system software reliability of 93.1% means that 6.9% of the operational time of any of the mentioned systems could be in failure or under repair. That is a high risk for the operation of BWTS and detection system verified in this study will be of great help in verification of results of performance of BWTS on ships.

5. Conclusion

Experience in operational ballast water management is hidden back data today. That is reasonable because of the profit in the maritime industry, marketing, reputation of shipping companies, ballast water treatment system inventors and institutes where the systems were tested and certified. Accidents data or malfunction and failure data of installed ballast water treatment systems are not available except to owners, classification companies or insurers. The only way for scientists to confirm proper performance of BWTS is to suggest control and supervision. Verification in this study helps to better understand a supervision system suggested in a previous research.

References

Albert, R.J.; Lishman, J.M.; Saxena, J.R. 2013. Ballast Water Regulations and the move toward concentration-based numeric discharge limits, *Ecol. Appl.*, 23(2): 289-300.

Aliotta, J.; Rogerson, A.; Campbell, C.B.; Yonge, M. 2001. Ballast Water Treatment by Electro-Ionization. In *Proceedings of the 1st International Ballast Water Treatment R&D Symposium*, 61-69.

Asai, R.; Otani, K.; Nakamura, C.; Ikebukuro, K.; Arikawa, Y.; Miyake, Y.; Karube, I. 2003. PCR-Based Ribosomal DNA Detection Technique for Microalga (Heterosigma carterae) Causing Red Tide and Its Application to a Biosensor Using Labeled Probe**,** *Marine Biotechnology*, 5(5): 417-423.

Bakalar, G. 2013. Automatic control system for ship ballast water treatment by using flow cytometry and satellite communications technologies, *PhD thesis*, 170 p. Rijeka University, Croatia.

Bakalar, G. 2014. Review of interdisciplinary devices for detecting the quality of ship ballast water, *SpringerPlus,* 1(3): 468.

Bakalar, G. 2012. A thesis on a remotely controlled BWTS, *The Ballast Water Times II*, *Journal of Institute NIOZ,* project NSBWO (North Sea Ballast Water Opportunity) project financed by EU, EK: 3 p.

Bakalar, G. 2011. Efforts to develop a ballast water detecting device. In *Proceedings of Global IMO R&D Forum on Compliance Monitoring and Enforcement*, 117-126.

Bakalar, G.; Baggini, M.B. 2016. Automated method and system for monitoring the performance and continuation of ballast water treatment system operation on ships. In *Proceedings of 58th International Symposium ELMAR*.

Bakalar, G. 2012a. Possibility of Remote Monitoring BWTS Quality. In *Proceeding of IMO ICBWM 2012 Globallast R&D Forum*, Singapore.

Bakalar, G. 2015. The System of Remote Control of the Automatic Detection of Ship's Ballast Water via Satellite Communication from Land, *Patent app.*, HR P20150144A.

Bakalar, G.; Tomas, V. 2016. Possibility of Using Flow Cytometry in the Treated Ballast Water Quality Detection, *Pomorski zbornik,* 51(1): 43-55.

Bakalar, G.; Baggini, M.B. 2016a. Automatic communication system ship to shipping terminal, for reporting potential malfunctions of a ballast water treatment system operation. *In Proceedings of 39th International Convention MIPRO*.

Bakalar, G. 2016. The system of automatic and autonomous flow and quantity measurement for detection of stoppage of ballast water treatment system operation, *Patent app.,* HR P20160144A.

Bakalar, G.; Tomas, V.; Bukša, A. 2011. Monitoring of chemical pollution from the ships in coastal area. In *Procceedings of Abstracts of International Conference on Climate Friendly Transport, Shaping Climate Friendly Transport in Europe, Key Findings & Future Directions*: 41 p.

Bakalar, G. 2016a. Comparisons of interdisciplinary ballast water treatment systems and operational experiences from ships, *SpringerPlus*, 5(1): 240.

Bakalar, G.; Tomas, V. 2011. Possibility of using satellite communication technologies for remote maintenance in marine industry, 5th GNSS Vulnerabilities and Solutions Conference.

Bakalar, G. 2011a. Intensifying efforts for furthering safety culture in shipping - training aspects. In *Proceedings of International conference IMLA 19*, 63-70.

Choi, W-J.; Kim, C-H.; Choi, H-M.; Lee, K-S.; Choi, W-J.; Kim, J-M. 2014. Trend Analysis and Diagnosis for BWTS Remote Monitoring, IEMEK *Journal of Embeded Systems and Applications*, 9(3): 127-135.

Cvetković, M.; Grego, M.; Turk, V. 2016. The efficiency of a new hydrodynamic cavitation pilot system on Artemia salina cysts and natural population of copepods and bacteria under controlled mesocosm conditions, *Marine Pollution Bulletin*, DOI: 10.1016/j.marpolbull.2016.01.030.

Cvetković, M.; Kompare, B.; Krivograd Klemenčić, A. 2015. Application of hydronamic cavitation in ballast water treatment, *Environmental Science and Pollution Research*, 22(10): 7422-7438.

Environmental Protection Agency (EPA), 2011. Efficacy of Ballast Water Treatment Systems: a Report by the EPA Science Advisory Board. Available from Internet: <www.EPA-SAB-11-009-unsigned.pdf>.

Globallast, 2016. Available from Internet: <http://globallast.imo.org/index.asp?page=mepc.htm&menu=true>.

Grob, C.; Pollet; B.C. 2016. Regrowth in ship's ballast water tanks: Think again!, *Marine Pollution Bulletin*, DOI: 10.1016/j.marpolbul.2016.04.061.

Kim, C--H.; Kim, J.-M.; Kim, B.-C.; 2014. Remote Communication of sensor data in Ballast Water Treatment System, *The Journal of The Institute of Internet, Broadcasting and Communication*, 14(6): 139-147.

La Carbona, S.; Viitasalo-Frösen, S.; Masson, D.; Sassi, J.; Pineau, S.; Lehtiniemi, M.; Corroler, D. 2010. Efficacy and environmental acceptability of two ballast water treatment chemicals and an alkylamine based-biocide, *Sci. Total. Environ,* 409(2): 247-255.

Liebich, V.; Stehouwer, P.P.; Veldhuis, M. 2012. Re-growth of potential invasive phytoplankton following UV based ballast water treatment, *Aquatic Invasions*, 7: 29-36.

Lloyd's, 2014. Ballast water treatment technology - current status, Available from Internet: <http://www.lr.org/en/_images/213-35824_Understanding_Ballast_Water_Management_0314_tem155-248816.pdf>.

Macintyre, H.L.; Cullen, J.J. 2016. Classification of phytoplankton cells as live or dead using the vital stains fluorescein diacetate and 5-chloromethylfluorescein diacetate, *Journal of Phylology*, DOI: 10.1111/jpy.12415.

Perrins, J.C.; Cooper, W.J.; van Leeuwen, J.H.; Herwing, R.P. 2006. Ozonation of seawater from different locations: formation and decay of total residual oxidant implications for ballast water treatment, *Marine Pollution Bulletin*, 52: 1023-1033.

Ren, Z.; Zhang, L.; Leng, X.; Shao, J. 2016. Effect and mechanism of a High Gradient Magnetic Separation (HGMS) and Ultraviolet (UV) composite process on the inactivation of microbes in ballast water, *Marine Pollution Bulletin*, 108(1): 180-185, DOI: 10.2016/j.marpolbul.2016.04.032.

Schreiber, U. 2004. Pulse-Amplitude-Modulation (PAM) Fluorometry and Saturation Pulse Method: An Overview, *Advances in Photosynthesis and Respiration*,19: 279-319.

Simpson, G. 2001. Ballast water disinfection with ClO2. In *Proceedings of the 20th International Conference on Marine Biology*, 131 p.

Sutherland, T.F.; Levings, C.D.; Petersen, S.; Hesse, W.W. 2003. Mortality of zooplankton and invertebrate larvae exposed to cyclonic pre-treatment and ultraviolet radiation, *Marine Technology Society Journal*, 37: 3-12.

van Der Star, I.; Liebig, V.; Stehouwer, P.P. 2011. The importance of organisms smaller than 10 µm. In *Proceedings of Global R&D Forum on Ballast Water Management*, 41-50.

CROSS-TABULATION OF THE TOWS MATRIX: A NOVEL DIMENSION FOR ASSESSING THE COMPETITIVENESS OF MARITIME CLUSTERS

Peter J. Stavroulakis[1], Stratos Papadimitriou[2], Elena Riza[3]
[1,2] Department of Maritime Studies, University of Piraeus, Piraeus, Greece
[3] Medical School, University of Athens, Athens, Greece

Abstract: Industrial clusters have for decades been considered as a predominant sanctuary for competitiveness; a kind that is generated through symbiotic characteristics that are disposed to flourish through innovation dynamics. The research extract, that within industrial clusters, knowledge creation and innovation that lead to competitiveness are able to thrive, comes effortlessly. Within an industrial cluster the scarcity principle nearly vanishes and competitiveness may be attained through collective prosperity. Maritime clusters in particular can be considered as rudimentary in the formulation of regional strategic advantages, primarily due to the fact that the maritime sector holds a distinct and prevalent effect within any given economic cycle. Within the instruments formulated for industrial cluster research, the ones pertaining to strategic management do stand out, since effective strategy is a major factor of influence towards the health of an industrial cluster. It would seem that sustainable, adaptive and innovative strategy is what sets these clusters apart, majorly due to the fact that only within a strategic interpretation, can the opulence of a maritime cluster move into focus. Within this context, maritime clusters provide a rich framework for the generation and assessment of quantitative and qualitative methodologies and instruments; the present work aspires to contribute within this particular body of knowledge. The very useful TOWS matrix that can stand as the factor responsible for effective strategy formulation, is paired with cross-tabulation methodologies in order to relish the latter's arsenal of analytical potential. By introducing cross-tabulation within the TOWS matrix, an array of calculations can be relinquished that will in turn facilitate the process of strategy formulation. The application of this model may prove to be the instigator of sustainable competitiveness within a particular cluster, but furthermore, the instrument may find applicability within a plethora of strategic management cases.

Keywords: maritime cluster, competitiveness, strategic management, TOWS matrix, crosstab.

1. Introduction

Industrial clusters are the object of study and subsequent admiration, due to the fact that within them, a plethora of agreeable attributes, characteristics and dynamics, may not only reside, but thrive nonetheless. For instance, within industrial clusters, there seems to find solace a continuum that extracts instances of mutual opulence and collective prosperity. These traits, that seem to be shared within all efficient industrial clusters, suggest that within these industrial entities, a critical mass of innovation dynamics gives birth to sustainable competitive advantages for the firms within. These sustainable competitive advantages would not or could not reside outside the cluster. This goes to show that a firm that maybe would toil within any given setting, might thrive within an industrial cluster. This reincarnates industrial clusters to symbolizing beacons of collectiveness and mutuality. Thus the arrival to an industrial cluster's first paradoxical instance, that of the degeneration of the scarcity principle, leading to an evident scarcity paradox. This paradox would be the initial stance of analysis, for within it lies the key to understanding both the threads of industrial clusters and the caveat of the scarcity principle as well. As a firm pillar of economic theory, the scarcity principle stands to provide a given moral stand, as well as a latent underlying philosophy, that within a given geographical location, the quantity of resources is not infinite.

The aforementioned creed, that within a given location all natural resources should be treated as scarce, may pose as a discrete thread of a much needed requisition of respect towards the natural environment, by not treating proximity as an ever providing system; alas, within an industrial cluster it is just not applicable. This primal conflict of industrial cluster activity does pose itself as a paradoxical element, should an analysis consider the scarcity principle as a given. That the scarcity principle should be embedded in the foundation of any analytical query, is a proposition that does hold water, for it provides a quasi-level playing field for any proximate members. It also, for a kind, sets the tone of competitive dynamics within the proximate geographical location, for all stakeholders are aware of the resources that are to be exploited in order to obtain a competitive advantage. By extension, and taking under consideration modern strategic management thought, while a firm will promote its distinctive competence in order to obtain a sustainable competitive advantage, she will proceed to compete with other firms that are active within the given operations theatre. This understanding provides a very simple model for the interaction and subsequent evolution of proximate competition; since a resource is finite, the firms will compete for the given amount of the distinct resource. By extension, a question may surface as to the procedure that will be followed when a resource will render itself obsolete. Of course one could argue that the willing manifestation of the post-scarcity era will be the fixation and subsequent competition for another scarce resource, but through this prism a vicious cycle does emerge. As firms within a given proximity simply drain natural and other resources within a continuum, the question of sustainability surely becomes evident. Since firms strive for permanence and sustainable operations (that they themselves will reinforce the existence of the firm), the paradigm of resource scarcity does surrender its appeal and a novel understanding of sustainable activity may be afoot.

Within an industrial cluster setting, there seem to be a plethora of conflicting stakes that thrive altogether. The difference may be that any if not all resources pertain to potential resources and thus are utilized as before, but with the important distinction of life cycle continuity. This differentiation uncovers a basic latent ideal that can be found

[1] Corresponding author: pjstav@gmail.com

embedded in industrial clusters and many natural systems at large, that is, the culture of mutualism. Within industrial clusters, there are no destructive dynamics, but rather, a plethora of entities that coexist as one system, wherein the traditional understanding of scarcity theory is enriched with knowledge creation and innovation, that in turn facilitate the blossom of collective activity and unity that is engorged in a cluster. All the notions presented could not come to pass without that most basic characteristic of clusters, strategic management; the basis for all inherent activity within a cluster, is strategy. Strategic management is the catalyst that will facilitate all mutualistic dynamics and will formulate the sustainable competitive advantage of all entities within the cluster, to the point that it will seem that the competitive advantage belongs to the cluster itself. Within this domain, strategic management is the facilitator of competitiveness, through the formulation of quantitative and qualitative instruments that are tailored in order to assess and model the aforementioned competitiveness. This work pertains to such instruments, as it entails a novel approach as to the utilization of the TOWS matrix, an effective instrument of strategic management.

2. Strategic Management and Maritime Clusters

Industrial cluster dynamics come to alleviate the requirement of a more sustainable and constructive paradigm, through contesting the scarcity principle. The understanding of zero-sum eventualities that is adamant within a scarcity principle-woven world, is deconstructed and replaced with a dynamic and diverse culture of symbiosis, exact to natural occurrences. In nature, the paradigm of resource scarcity simply does not exist in the abstract, only in the absolute. That goes to say that in most, if not all natural systems, abundance is more evident than scarcity (McDonough & Braungart, 2002) and all activity is focused on obtaining a sustainable competitive advantage against predatorial eventualities, albeit environmental or systemic. But all this activity does not render the geographical proximity scarce, but conversely more versatile and rich. It is as though all entities through striving towards individualistic survival, contribute towards the evolution of the whole super-system; that there exists a latent systemic drive within these natural constructs, that enables collective prosperity rather than zero-sum games. A first observation should be that these occurrences may not hold an infinite life span; these systems portray the aforementioned extraordinary qualities for a time within their span of activity and not within an infinite continuum. Thus, nature will foster initiation or birth, growth, maturity and decay (again, exactly as within clusters) in a cyclical manifestation and for all levels of focal length, albeit a resource, an entity, or the sum of all systems that compose nature. A subsequent observation would be that there is evident correlation with Adam Smith's (1776) notorious 'invisible hand' and all its eventual corollaries, since (within industrial clusters) individual good is found to *somehow* guide the collective benefaction of the region.

The notion of the evident correlation of natural systems' dynamics with the absence, albeit paradox, of the scarcity principle, along with the eventuality of unhindered (and healthy) activity, that builds towards sustainable and collective mutualism, provides the cornerstone of industrial cluster theory. Thus, the two basic pillars that are mutually inclusive within industrial clusters, emerge as the circumvention of the scarcity principle, through a mechanism and process that is maybe not that transparent and a culture of self-maintenance, that again, through an oblique process, tends towards individual as well as collective tenacity, at least with respect to survival and evolution. A first attempt for understanding both these elements, could emerge from the apparent realization that the scarcity principle is self-evident. There is no way to create energy ex nihilo, as is dictated by the first law of thermodynamics and the law of the conservation of energy. As the first law of thermodynamics is the application of the law of conservation of energy for thermodynamic systems, so is the scarcity principle an application of the same law, but for systems of economies. As an isolated system for thermodynamics cannot produce energy but can only transform it, so do economies utilize finite resources and transform them into commodities, services and need-fulfilling items. Since the scarcity principle has such an airtight case, one must ponder the superficial divergence of industrial clusters from it and hazard a rational explanation for this discrepancy.

An initial explanation would situate itself as the eventuality that there are exceptions to the principle and that many natural systems that seem to break the scarcity principle by offering collective prosperity, are just instances of the scarcity principle's non-inclusion and thus, both the scarcity principle theory and many an instances where it is not applicable can be valid simultaneously. A deeper investigation as to the issue though, may reveal not only the absence of exception from the principle, but an absolute adherence towards its foundation. In order to explore this argument, one must backtrack to the law of conservation of energy. The law states that an isolated system cannot create and/or destroy energy, but merely transform it from one form into another, all the while keeping the sum of all energy a constant. If the sum of energy is to remain constant, thence the implicit conclusion with respect to resources is that they are neither created nor destroyed, rather transformed. Within this transformation, the initial form of the resource diminishes, leading to the point that this may be rendered exhausted. That a resource has been spent, in no way implies that it has been destroyed, or that another has been created from scratch, rather, that all resources may be undergoing a plethora of transformations within their life-cycle. Thence the question remains, why there resides a possibility that within a given geographical location and for a given time span, there seem to be competing entities all thriving simultaneously, within a given and finite number of natural resources, all with the scarcity principle valid. The answer is as credible as it is effortless. The entities do not compete upon a given amount of resources; they compete upon what may be considered a resource in the first place. Through this prism, the law of conservation of energy and the scarcity principle are not violated within any given scenario. Thus, the issue becomes one of visibility, or rather, of the ability to realize what a resource may entail.

Through this argument, one may ponder that the only way for a self-evident law of nature to remain un-breached and an apparent manifestation of collective prosperity (that is indisputable in so many natural systems) to be explained, is to reconsider what a resource entails in the first place. The narrow approach will discard mutualism as a discordance, an unyielding violation of a sound principle, whereas through a more inclusive approach, the at first paradoxical nature of collective sustainability will explain itself as a mere variation of the same principles. Thus, it will be a question of interpretation and subsequently, culture, if and how the scarcity principle is violated within an industrial cluster, for it is not only conflicted, but diligently adhered-to, nonetheless. At first viewing, the scarcity principle will pertain to the finite number of resources that have to be competitively and rigorously claimed by a different number of entities that are active in a particular field. At a subsequent level of detail, collective prosperity may be achieved within a given geographical location of finite resources by a growing number of firms, whence what may be conceived as such is regenerated. The only eventuality of the materialization of this version of the scarcity principle, is through a never ending plight that will reincarnate as the constant struggle of novel methods, ideas and solutions; what is widely considered to be the process of innovation. If the constituent of innovation is added to the threads of scarcity theory, thence the latter is not only not contested within so many natural systems that show such semblance to industrial clusters, but is adamantly reinforced, along with its backbone, the law of conservation of energy. All this theory requires to manifest any effectiveness and materiality, is the catalyst of strategy.

The basic approach of the latest years with respect to industry clusters, was the realization of the importance of strategic management within. From the rudiments of the theory, strategic management threads are apparent, but its explicit mention can only be traced in recent decades. Though Alfred Marshall (1890/1920), the first of neoclassical economists (Pinto, 1975), is mostly noted to have commenced the threads of modern industrial cluster theory, the father of location theory, von Thünen (1826), provided an excellent model for the effective concentration of economic activity. Within his work, there is mention of the appeal that Adam Smith's (1776) work had imposed. Smith's amazing construct of the 'invisible hand' that will guide a 'domestic industry' towards prosperity does formulate resonance to what today we would coin as industrial cluster dynamics. Thus, though Adam Smith is not formally attributed with an explicit contribution to the theory, there can be observed a correlation with his most infamous mention and cluster specifics. The entanglement of industrial clusters with instances that lean towards the paradoxical and the mysterious are merely one trait of clusters that facilitated many requirements for the emergence of strategic management. The latter is the vessel that pertains to the deconstruction of industrial clusters' obscurity, into analytically enabling traits. These obscurities are apparent in modern theory as well, many times in the form of paradoxes, such as the location paradox (Porter, 2000).

Though the cluster concept is not without caveats, albeit with respect to its applicability to specific industries (Steinle & Schiele, 2002), or with reference to the theory itself (Ortega-Colomer, 2016), recent research converges to the notion that maritime clusters provide inherent sources of regional competitive advantage (Antonopoulos, 2016). Even though the main industry from which the cluster has emerged may differentiate itself, regional competitiveness does seem to stem from an industrial cluster capacity (Doronina et al., 2016). The agreement always seems the same, that the fuel of clusters is innovation (Mazur et al., 2016). This process may very well be the output of an innovation system, or based on a specific constituent of innovation, such as collaborative innovation (Schaffers et al., 2016). Clusters do require severe scrutiny as to the process of innovation and provide a plethora of analytical potential thereof (Xie et al., 2016). Whichever the case, industrial clusters seem to be very important for strategic management (Dewally & Shao, 2015). This may be due to the fact that practice shows that one has a great influence over the other (Schiele, 2008), to the point that they may be intertwined with innovation dynamics as well (Rocha et al., 2010). Organizational adaptation may be added to the list (Niu, 2010), along with trust (Niu et al., 2012) and information networks (Casanueva et al., 2013), as drivers of industrial clusters' strategic management.

3. Cross-tabulation of the TOWS Matrix

The TOWS matrix (Fig. 1.) can be utilized as an effective instrument for mapping the different strategies available to an entity that is active within an industry cluster. Within a maritime cluster, it can pose as an extremely beneficial aspect of the strategy formulation process. Its potential strategic combinations are its major asset, for among the combinations of strategy, a firm may find a pertinent one and through this, benefit the cluster's super-system. Along with the SWOT analysis methodology, that is TOWS preceding step, the strategy formulation process for a maritime cluster can be streamlined and efficient. The methodology is utilized extensively within maritime clusters, albeit from a port perspective (Zauner, 2008), or within the focal length of a national cluster (Nordic Centre for Spatial Development, 2016). The analysis may be utilized within the exploration capacity of potential growth drivers (Danish Ministry of Economic and Business Affairs, 2006), or for analyzing national competitiveness (ECOTEC Research & Consulting, 2006). As SWOT analysis is utilized formally to present an analytical view for situation analysis, the TOWS matrix may be utilized as its progression, towards strategy formulation.

Through the utilization of the TOWS matrix, an analytical quantitative constituent may be absent and this may pose a hurdle for the efficient utilization of the instrument. This drawback may subside if cross-tabulation is introduced within the TOWS matrix items. The TOWS matrix results may be quantified and summed; for any item of the matrix, its quantitative elements may formulate a sum, such as, $a = \Sigma\ SO_n = SO_1 + SO_2 + \ldots + SO_n$, rendering a numerical result for each category. Thence, a basic crosstab (Fig. 2.) may be formulated.

Internal Origin / External Origin	Strengths	Weaknesses
Opportunities	SO Strategies	WO Strategies
Threats	ST Strategies	WT Strategies

Fig. 1.
The TOWS matrix
Source: Authors

The categorical variables of the crosstab can be the general categories of the TOWS matrix, or the preceding SWOT analysis items. Through this methodology, a novel instrument is relinquished, with the potential to portray different interpretations of the quantitative items. Through the numeric and statistical manipulation of items within the crosstab, statistical decision tests and risk factors may be calculated and interpreted, in order to portray any relevance and interdependence between the categorical variables. For example, basic measures of association can be extracted, based on the type of strategy formulation or case that is pursued.

Categorical variable 1 / Categorical variable 2	State 1i	State 1ii
State 2i	$a = \sum_{n=1}^{n_{SO}} SO_n$	$b = \sum_{n=1}^{n_{WO}} WO_n$
State 2ii	$c = \sum_{n=1}^{n_{ST}} ST_n$	$d = \sum_{n=1}^{n_{WT}} WT_n$

Fig. 2.
A generic crosstab
Source: Authors

Within crosstabs' plethora of methodological instruments, measures of association stand out as simple and practical items that enable the analysis with further informative potential. Especially for maritime clusters, measures of association can signify strategic essence, since they will provide readily available factors that guide any indication of association between the items of the crosstab. The attributable risk (AR = a – c = SO - ST) will show the relevance of the external environment within the formulation of strategies. The risk ratio [RR = a * (c + d) / c * (a + b) = SO * (ST + WT) / ST * (SO + WO)] will manifest the favorability of strengths with respect to opportunities, to that with reference to threats. Consequently, the odds ratio [OR = (a / c) / (b / d) = a * d / c * b = SO * WT / ST * WO] will present the impact of the external opportunities in creating favorable instances. In addition to measures of association, a plethora of further calculations may be administered, thus forming a calculatory arsenal that can be tailored with respect to given strategy formulation requirements.

4. Conclusion

A cost-effective methodology is relinquished that may hopefully prove to be effective in its practical utilization, within the domain of strategy formulation, in maritime clusters. Through the calculatory potential introduced by cross-tabulating the TOWS matrix, a plethora of statistical calculations may be administered, that will provide further guiding and decision making tools for the formulation of strategy within maritime clusters. The model is constrained by the limitation that in order for it to function, a quantitative understanding of the case must be portrayed. The latter may be susceptible to random as well as systematic error, not to mention error propagation. These hurdles may be overcome with diligent and materialistic processes, that will guide operations towards the effectiveness of strategy. Through this process, the competitiveness of maritime cluster members, as well as the competitiveness of the maritime cluster itself, may be assessed and pertinent strategic directions may be outlined.

Acknowledgement

The publication of this paper has been partly supported by the University of Piraeus Research Center.

References

Antonopoulos, C.N. 2016. Why the New Maritime Geographies Matter, *Geography Compass*, 10(8): 346-359.

Casanueva, C.; Castro, I.; Galán, J.L. 2013. Informational networks and innovation in mature industrial clusters, *Journal of Business Research*, 66(5): 603-613.

Dewally, M.; Shao, Y. 2015. Industry cluster and performance sensitivity, *Journal of Economics and Finance*, 39(4): 824-844.

Doronina, I.I.; Borobov, V.N.; Ivanova, E.A.; Gorynya, E.V.; Zhukov, B.M. 2016. Agro-industrial clusters as a factor of increasing competitiveness of the region, *International Journal of Economics and Financial Issues*, 6(1S): 295-299.

ECOTEC Research & Consulting, 2006. An exhaustive analysis of employment trends in all sectors related to sea or using sea resources - Method report for the European Commission, DG Fisheries and Maritime Affairs. Available from Internet: < http://ec.europa.eu/maritimeaffairs/documentation/studies/documents/methods_report_en.pdf>.

Marshall, A. 1920/original work published in 1890. *Principles of Economics; An Introductory Volume*. Macmillan and Co., London, U.K.

Mazur, V.V.; Barmuta, K.A.; Demin, S.S.; Tikhomirov, E.A.; Bykovskiy, M.A. 2016. Innovation clusters: Advantages and disadvantages, *International Journal of Economics and Financial Issues*, 6(1S): 270-274.

McDonough, W.; Braungart, M. 2002. *Cradle to cradle*, North Point Press, N.Y, U.S.A.

Ministry of Economic and Business Affairs 2006. The Danish Maritime Cluster – an Agenda for Growth. Available from Internet: < http://www.dma.dk/sitecollectiondocuments/publikationer/danish-maritime-cluster-uk.pdf >.

Niu, K.-H. 2010. Industrial cluster involvement and organizational adaptation: An empirical study in international industrial clusters, *Competitiveness Review*, 20(5): 395-406.

Niu, K.-H.; Miles, G.; Bach, S.; Chinen, K. 2012. Trust, learning and a firm's involvement in industrial clusters: A conceptual framework, *Competitiveness Review*, 22(2): 133-146.

NORDRIEGO (Nordic Centre for Spatial Development), 2016. The Swedish Maritime Cluster, Description and analysis of the economic importance and international competitiveness of the Swedish Maritime Cluster. Available from Internet: <http://www.nordregio.se/en/Nordregio-Research/The-Swedish-Maritime-Cluster/>.

Ortega-Colomer, F.J.; Molina-Morales, F.X.; de Lucio, I.F. 2016. Discussing the concepts of cluster and industrial district, *Journal of Technology Management and Innovation*, 1(2): 139-147.

Pinto, J.V. 1975. *Background and Development of Location Theory*, Ph.D, Dissertation, The University of Oklahoma, Oklahoma, U.S.A.

Porter, M.E. 2000. Location, competition, and economic development: Local clusters in a global economy, *Economic Development Quarterly*, 14(1): 15-34.

Schaffers, H.; Gatautis, R.; Penttinen, H.; Szalavetz, A.; Tancig, P. 2006. Emerging value clusters in the New Member States: The role of collaborative innovation. In *Proceedings of the 2006 IEEE International Technology Management Conference, ICE 2006*.

Schiele, H. 2008. Location, location: The geography of industry clusters, *Journal of Business Strategy*, 29(3): 29-36.

Smith, A. 1776/2007 edition. *An Inquiry Into the Nature and Causes of the Wealth of Nations*. MetaLibri Digital Library.

Steinle, C.; Schiele, H. 2002. When do industries cluster? a proposal on how to assess an industry's propensity to concentrate at a single region or nation, *Research Policy*, 31(6): 849-858.

Von Thünen, J.H. 1826. *Isolated State*, Pergamon Press, New York, U.S.A.

Xie, X.M.; Wu, Y.H.; Ma, G.X. 2016. Driving forces of industrial clusters towards innovative clusters: accelerating the innovation process, *Asian Journal of Technology Innovation*, 24(2): 161-178.

Zauner, A. 2008. Strategic port planning: A case study of the Rotterdam seaport cluster applying the SWOT framework, *Journal für Marketing*, 47(3): 130-141.

ANALYSIS OF THE NAUTICAL RISK ASSESSMENT IN PASSENGER PORTS

Maja Škurić[1], Vladislav Maraš[2]
[1] *University of Montenegro, Maritime Faculty, Kotor, Montenegro*
[2] *University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia*

Abstract: This paper investigates the identification of potential risks for the performance of maritime passenger transport activities in the ports. Passenger ports especially cruise ship ports in Adriatic Sea are facing with the constant growth in the passenger throughput over the last decade. The navigational safety traffic is characterized of the utmost importance. In this paper we try to quantify the possibilities for risk assessment occurrence of accidents of passenger ships including cruise and ferry ships especially in the narrow coastal areas such as Boka Kotorska Bay area in Montenegro. Here we concentrate on experts' judgments regarding the risk events' occurrence in the cruise port of call Kotor. According to their opinion we estimate the frequencies and consequences of possible risk events, such as collisions, groundings and so on. The results of this analysis enable the determination of the risk occurrence of accidents in the reported area. Finally, the proposal for the new scenario regarding the cruise ships servicing in Boka Kotorska Bay to increase navigation safety and security in passenger ports is specified.

Keywords: risk, passenger port, cruise ships, ferry ships.

1. Introduction

In this paper the nautical risk assessment in the case of Kotor cruise port (Boka Kotorska Bay, Montenegro) is investigated. We develop a model that is based on experts' judgment in relation to the frequency and consequence of risk events in defined navigational area. Also, we provide few numerical experiments as well as we propose some suggestions for avoidance of risk events when cruise ships would be serviced outside the Kotor Bay. For the realization of the specified problem, it is necessary to collect the appropriate data, identify the possibilities of risk event and propose a model. Therefore, the main goal of this research is directed to the identification of possible risks, the risk probability and the possibility of repeating the risk event after some period of time. The expert judgment provided in this analysis included consultations with pilots and ship's captains in order to separately give the estimation of the frequency and consequences of different risk events, namely: ship's collision, overtaking, grounding, navigation error, bad weather conditions and ship's breakdown.

The analysis of nautical risk assessment is investigated a lot in the previous period. Ships need to respect the rules of navigation especially in restricted and limited navigation area that represents narrow passage, so the general safety of all participants has to be provided. From the mathematical point of view, ship collision is described by geometric distribution (Debnath and Chin, 2010; Li et al., 2012; Montewka et al., 2010; Pedersen, 2002, 2010; Seong, 2012; Tan and Otay, 1999). Fowler and Sorgard (2000) evaluated that the accident is occurring as a result of the encounter between two ships and those are treated to be independent and different events. According to the analysis done by United States Coast Guard USCG (1999), different ships' encounters were discussed. Generally speaking, ship can change its speed and course in order to avoid the collision (Merrick et al., 2002). On the other side, some authors used automatic identification system in order to determine the level of congestion of maritime traffic in narrow passages. Their results were useful from the macroscopic maritime traffic modeling point of view. Main role of ships in modeling the avoidance of collisions is described and reported in Fujii and Tanaka (1971).

This paper is structured through five sections. In Section 2, the navigation area is described. Nautical risk assessment model with the appropriate parameters is provided in Section 3. Experimental analysis that includes the numerical examples with the proposal of new scenario of cruise and ferry ships' servicing in port is reported. Final section gives concluding remarks.

2. Navigation area

Kotor cruise port records the increased traffic volumes of cruise ships and is mostly oriented to nautical tourism. Likewise, Boka Kotorska Bay is situated in the southwest part of Montenegro. Nautical chart of the Bay is shown in Fig. 1. As it can be noticed, the Bay is divided into the four minor: Kotor, Risan, Tivat and Herceg-Novi. Upon the entrance, ships are passing through the Herceg-Novi Bay. The inner bays are the rest ones. In the Kotor Bay is located cruise port of call Kotor, recently recognized as a very popular place for tourists visit by ship. Therefore, the Kotor port was oriented to the cruise tourism. Approximately, it takes two hours that ship arrives to the port. Pilot station is located in Zelenika, 12.3 nautical miles from the Kotor port. The maximal ships' speed is 12 knots while entering to the pilot station, it reduces to 8 knots. At the beginning of the Kotor Bay, the speed of ships is only 4 knots. The conditions of safe ships moving inside the bay are provided due to the very well weather and nautical issues during the whole year. The maximal time of ships' maneuvering is around half an hour. Average depth in Kotor Bay is from 15 to 18 meters (Dragović et al., 2014, 2015; Kofjač et al., 2013; Škurić and Maraš, 2016).

[1] Corresponding author: Maja Škurić; email: majaskuric@gmail.com

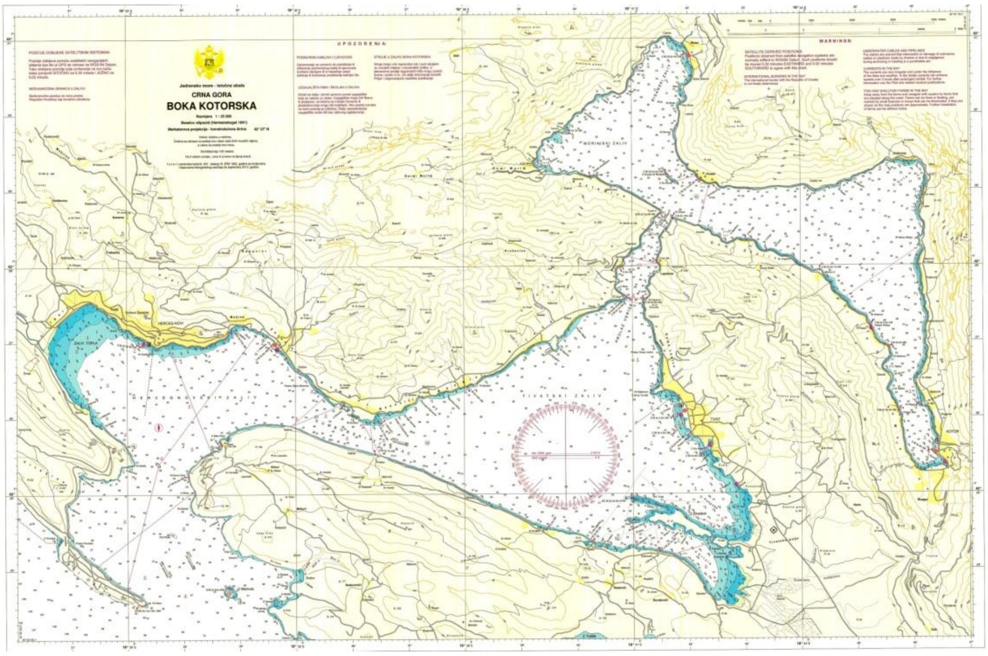


Fig. 1.
Nautical chart of Boka Kotorska Bay (PKAD, 2015)

Cruise ships in Kotor cruise port are servicing at the main berth, smaller river berth and two anchorages. At main berth, ships with length of 280 meters and draft of 8 meters can be serviced. Otherwise, ships are serviced at anchorages because there are no limitations in the ships' dimension. Ships with length of maximally 125 meters and draft of 4.5 meters are serviced at river berth. Anchorages are located 0.28 and 1.1 nautical miles from the port in Kotor Bay and frequently due to the operational policies, the anchorages are very used for ships' servicing. In addition, the trend of increased traffic is noticeable. In 2006 the total number of port calls of cruise ships was 155 while in 2015, 411 ships with around 440 thousand passengers visited Kotor cruise port. The average year increase in ships' traffic is 29%. The most frequent months are August, September and October. Sometimes, five or six ships per day are serviced in Kotor Bay area. Finally, the average number of passengers per ship call in 2006 was 235; in 2011 it was 600, while in 2015 it was 1075. In the case of servicing ships at anchorages, the port is using tendering service that implies lifeboats with capacity of 50 passengers for their embarking and disembarking.

3. Nautical risk assessment model

The quantification of nautical risk includes: identification of risk event, determining the probability of risk event, defining the loss rate produced by risk event and determining the risk rate. After the identification of risk event, it is necessary to designate its probability and quantify the loss that the risk event can produce. These are the basic indicators of the risk. The main methodologies for determining the level of risk are based on statistical data or expert judgments (Savić and Stanković, 2012). The first one is based on the probability theory while other on expert assessment. In this paper, we apply the second one. The probability of risk event P_e is in function of relative frequency of risk events is:

$$\mathrm{P_{re}} = R_e / n_{re} \tag{1}$$

Where; R_e: represent the number of risk events of the same type during a specified period of time, n_{re} is a number of possible realization of risk events in the same period. The values of risk events probability are from 0 to 1. Loss rate (number of passengers that are exposed to the risk event) in navigational area represents the mean of number of passengers that are participating in the same risk event (Savić and Stanković, 2012):

$$\mathrm{L} = \frac{1}{R_e} \sum_{j=1}^{R_e} L_j \tag{2}$$

Where; L_j: represents the rate loss caused by risk event j.
In this investigation, we apply the expert assessment on whose experience, knowledge and intuition is possible to meet the nautical risk in Boka Kotorska Bay. Beside the data of cruise ships' arrivals, here we assume that the local maritime transport of passengers from cruise ships is assigned to ferry passenger ships that are transferring tourists to the local ports. This methodology is used because of the insufficient information about the nautical risk probability, so it is

possible to model the realization of risk events. According to findings provided by Sulaiman et al. (2011) and Zaman et al. (2015), the classification of risk events is given in Table 1.

Table 1
Quantification of risk events' frequency

	Description	Probability of risk event
Negligible	Less often than once in 1000 years	$P_{re} \leq 0.001$
Small	Once between 100 and 1000 years	$0.001 \leq P_{re} \leq 0.01$
Occasionally	Once between 10 and 100 years	$0.01 \leq P_{re} \leq 0.1$
Probably	Once between 1 and 10 years	$0.1 \leq P_{re} \leq 1 \geq$
Frequently	Once or more during a year	$P_{re} \geq 1$

In this case, the experts are giving their opinions about the frequency of risk events as well as loss rate of their realization. In that way we provide the data of expected value of nautical risk, i.e. number of passengers from cruise and ferry ships that can be exposed to risk in the period of one year. But, firstly it is necessary to calculate the coefficient of concordance between the experts' opinions. In the case that coefficient of concordance is greater than 0.7, it is treated that the consensus of experts is provided. Otherwise, the process of evaluation should be succeeded (Savić, 2013). Based on their opinions, the ranking of experts' assessment is calculated. In this case, the smallest rank is given to the less frequency assessed by the experts and also this risk event is causing the smallest loss. In the case that more risk events have the same frequency or are causing the same loss, they have the same rank. Ranking that does not contain the same rank levels of events are named to be strict ranking, while the ranking that contains the same rank levels is called free ranking.

The coefficient of concordance for strict ranking is dependent on the total value of designed rankings (C) and total value of possible ranking (C_m) (Savić and Stanković, 2012; Цхадая я Подосенова, 2008):

$$W_d = C / C_m \tag{3}$$

Where;

$$C = \sum_{j=1}^{m} \left(\sum_{i=1}^{m} r_{ij} - \frac{m(n+1)}{2} \right)^2 \tag{4}$$

and

$$C_m = \frac{m^2 n}{12} \left(n^2 - 1 \right) \tag{5}$$

Where; n: a number of risk events, m: a number of experts in the analysis and r_{ij} represents the rank that the expert i assigned to the risk event j. In the case of free ranking, the coefficient of concordance is (Savić and Stanković, 2012; Цхадая я Подосенова, 2008):

$$W_f = C / C'_m \tag{6}$$

Where the total value of possible ranking is

$$C' = \frac{m^2 n}{12} \left(n^2 - 1 \right) - \frac{m}{12} \sum_{i=1}^{m} \left(\sum_{k=1}^{s_k} \left(s_k^3 - s_k \right) \right) \tag{7}$$

Where; s_k:is the number of the same rankings in group of ranks k of expert i, s_k represents the number of the groups of the same ranking provided by expert i.

After the evaluation of experts' consensus, the next is to determine the most probable values of frequencies and loss rate as well as the mean values of all experts. The expected risk value is calculated (Savić and Stanković, 2012; Цхадая я Подосенова, 2008):

$$R = \sum_{j=1}^{n} \overline{f_{rej}} \, \overline{L_j} \tag{8}$$

Where; $\overline{f_{re_j}}$: a mean frequency of risk event j, $\overline{L_j}$: mean of rate loss produced by risk event j.

4. Results

In this section we present some experimental analysis for calculating the expected values of risks in Kotor cruise port, mainly in Kotor Bay, based on the data of achieved traffic volumes of ships and passengers during a year. Considering the fact that cruise ships are serviced at main and river berth, as well as at anchorages, all located in Kotor Bay, the traffic density is very high during a year. Accordingly, the frequency of maritime transportation in a day is approximately 10 hours (taking into account that beside the cruise ship transport, here we suppose that the ferry transport of passengers to the local ports inside the Bay is active) and we start the experimental analysis that in a one-year-time-period, the total number of considered ships is 2000 (PKAD, 2015).

On the other side, for calculation expected values of risk, we interviewed three experts (denoted as e_1, e_2, e_3, respectively). The output data of their opinions regarding risk events' frequency and risk events' consequence are shown in Tables 2 and 3. They gave the independent opinions for six different categories of risks: ship's collision (r_{e1}), overtaking (r_{e2}), grounding (r_{e3}), navigation error (r_{e4}), bad weather conditions (r_{e5}) and ship's breakdown (r_{e6}).

Applying expressions (3-7) we calculate the expected value of risk using expression (8) that represents the number of passengers per year that is exposed to risk events. After the obtained result, we classify the frequency of risk events (f_{re}), as well as we calculated the period between the realization of two consecutive risk events in Boka Kotorska Bay.

Table 2

Experts' estimation of risk events' frequency (number of events per year)

	f_{re1}	f_{re2}	f_{re3}	f_{re4}	f_{re5}	f_{re5}
e_1	14	13	12	15	11	16
e_2	15	12	12	12	11	13
e_3	15	11	14	14	12	16

Table 3

Experts' estimation of risk events' consequence (number of events per year)

	L_{re1}	L_{re2}	L_{re3}	L_{re4}	L_{re5}	L_{re6}
e_1	50	10	260	100	5	90
e_2	73	13	270	50	5	120
e_3	50	15	395	50	5	75

Ranking and calculation of expected value of risk dependent on frequency and consequence of risk events is done in MATLAB-u 7.12.0, and contains the following steps:

1. First is to determine if there are the same frequencies or consequences in experts' opinions. In the case that there is no such a data, we use strict ranking, i.e. we assign the ranks from the lowest rank (1) to highest rank (6). Otherwise, in the case of the same frequencies, we calculate the mean of rank positions and they will have the same rank (we use the free ranking). The same is applied to the consequences,
2. The consensus of experts' opinions in frequency estimation is based on table data and coefficient of concordance. The same holds true for the consequence estimation,
3. We calculate the coefficient of concordance and the output shows the consensus of experts' opinions,
4. We calculate the mean of risk events' frequencies and consequences,
5. The expected value of risk expressed in number of passengers per year that is exposed to risk is obtained.

Finally, the coefficient of concordance regarding risk events' frequency of the considered example is 0.8133 which indicates the consensus of experts' opinions. In the case of risk events' consequence, the coefficient of concordance is 0.9359. The expected value of risk is 7297 passengers per year. If we assume that the total number of passengers that visited Boka Kotorska Bay is 450 thousand, the probability of realization of risk event is 0.0162, which implies that 62 years would be a period between the occurrences of two risk events. From the data in Table 1, we can conclude that the risk events' frequency belongs to occasionally class.

Following the same methodology, in Table 4 we did an experimental analysis for three cases with the input of opinions of two and three experts and five and six risk events. In the case of five events, we exclude the one of ship's breakdown. The result for a period between the realization of two consecutive risk events (E_{re}) in Boka Kotorska Bay is also provided.

Table 4
Results of expected risk values (passengers per year)

	Frequency data per year					Results			
	m	***n***	***C***	**C_m (C'_m)**	**W_d (W_f)**	***R* (pass.)**	**P_{re}**	**Class**	**E_{re} (year)**
Case 1	3	5	60.50	82.50	0.73333	487	0.00108	Small	926
	Consequence data per year								
	3	5	72.00	90.00	0.8000				
	Frequency data per year					**Results**			
	m	***n***	***C***	**C_m (C'_m)**	**W_d (W_f)**	***R* (pass.)**	**P_{re}**	**Class**	**E_{re} (year)**
Case 2	2	6	49.52	68.00	0.7282	599	0.00133	Small	752
	Consequence data per year								
	2	6	58.50	69.00	0.8478				
	Frequency data per year					**Results**			
	m	***n***	***C***	**C_m (C'_m)**	**W_d (W_f)**	***R* (pass.)**	**P_{re}**	**Class**	**E_{re} (year)**
Case 3	2	5	32.00	38.00	0.8421	942	0.00209	Small	479
	Consequence data per year								
	2	5	30.50	39.00	0.7821				

On the basis of output results and in the real case circumstances where the cruise ships are serviced, while ferry ship transport is developed in Boka Kotorska Bay, it is very important to take into consideration that the traffic density would be higher than in the case of servicing cruise and ferry ships in other inner bays of Boka Kotorska. So, for example, ships' servicing in Tivat or Risan's Bay would reduce the traffic density and appearance of risk events. Consequently, it is general opinion that the congestion of maritime transportation only in Kotor Bay can lead to the implementation of risk events and possible frequency of risk events. Therefore, it is necessary to predict the traffic intensity of all ships in bay in order to avoid the risk situations and thus prevent the endangerment of human life in this narrow area.

4.1. Proposal for new scenario of nautical risk decrease

Following the assumptions of experts, the possible situation of reducing the risk probability in Boka Kotorska Bay relies in new scenario that would include the displacement of cruise and ferry ships servicing from the Kotor Bay into the others. In that case the traffic volume of ships would be transferred to Tivat or Risan Bay, accordingly. There are few arguments that justify this scenario because the most important reason is related to the narrow passage in Kotor Bay in the case of increased maritime transport. Also, based on experts' opinions, the possibility of servicing ships in other bays is characterized to be a logical move due to the burdensome nautical area near the Kotor cruise port. The same methodology that is described in Section 3 and applying this model of nautical assessment confirms that 284 years will be a period between the realization of two consecutive risk events in Boka Kotorska Bay.

5. Conclusion

This paper deals with the nautical risk assessment in Boka Kotorska Bay, located in Montenegro, recognized as one of the most important node of nautical tourism in this part of Adriatic. However, in 2015 Kotor cruise port records 411 port calls with 420 thousand passengers. Having in mind that cruise ships are servicing at main berth, river berth and two anchorages, it is very important to investigate the level of nautical risk in the narrow area such as Kotor Bay where the port is located. Here we provided the information of navigational area, also, proposed a methodology to calculate the nautical risk assessment based on experts judgments, and finally gave some numerical examples in the case of five and six different risk events.

However, the whole methodology is very useful and accordingly we classified the frequency of risk event and predicted the time between the two consecutive events. In addition, the results obtained from the analysis are directed to the number of passengers from cruise and ferry ships (that will be employed soon) that would be exposed to the risk. On the other hand, the investigations such as this can serve to improve the communication and navigation issues in order to minimize the risk events in the future. Safety conditions need to be satisfied especially in passenger ports such as Kotor. New scenario for minimizing risk events in Kotor Bay is proposed. Therefore, there is a lot of space for improvement of this methodology, so further studies can be directed to the aspect of communication and electronic equipment that can be employed in the Boka Kotorska Bay in order to decrease the possibility of risk event realization.

References

Debnath, A.K.; Chin, H.C. 2010. Navigational traffic conflict technique: A proactive approach to quantitative measurement of collision risks in port waters, *The Journal of Navigation*, 63(1): 137-152.

Dragović, B.; Škurić, M.; Kofjač, D. 2014. A proposed simulation based operational policy for cruise ships in the Port of Kotor, *Maritime Policy & Management*, 41(6): 560-588.

Dragović, B.; Tzannatos, E.; Tselentis, V.; Meštrović, R.; Škurić, M. 2015. Ship emissions and their externalities in cruise ports, *Transportation Research Part D, in Press* dx.doi.org/10.1016/j.trd.2015.11.007.

Fowler, T.G.; Sorgard, E. 2000. Modeling ship transportation risk, *Risk Analysis*, 20(2): 225-244.

Fujii, Y.; Tanaka, K. 1971. Traffic Capacity, *The Journal of Navigation, Cambridge: Cambridge Journals*, 24: 543-552.

Kofjač, D.; Škurić, M.; Dragović, B.; Škraba, A. 2013. Traffic modelling and performance evaluation in Cruise Port of Kotor, *Strojniški vestnik – Journal of Mechanical Engineering*, 59(9): 526-535.

Li, S.; Meng, Q.; Qu, X. 2012. An Overview of Maritime Waterway Quantitative Risk Assessment Models, *Risk Analysis*, 32(3): 496-512.

Merrick, J.R.W.; van Dorp, J.R.; Mazzuchi, T.; Harrald, J.R.; Saphn, J.E.; Grabowski, M. 2002. The Prince William Sound risk assessment, *Interface*, 23(6): 25-40.

Montewka, J.; Hinz, T.; Jujala, P.; Matusiak, J. 2010. Probability modelling of vessel collisions, *Reliability Engineering and System Safety*, 95(5): 573-589.

Pedersen, P.T. 2002. Collision risk for fixed offshore structures close to high density shipping lanes, *Journal of Engineering for the Maritime Environment*, 216(1): 29-44.

Pedersen, P.T. 2010. Review and application of ship collision and grounding analysis procedures, *Marine structures*, 23(3): 241-262.

PKAD (Port of Kotor A.D.). 2015. Port of Kotor A.D. Reports of 2015, Kotor, Montenegro.

Savić, S.; Stanković, M. 2012, *Teorija sistema i rizika*, Akademska misao, Beograd, Serbia

Savić, M. 2013. Metodologija razvijanja upitnika uz pomoć Delfi metoda na kursevima iz statistike, In *Vodič kroz metodologiju nastave primenjene statistike* (*Odabrana poglavlja iz metodologije nastave primenjene statistike*), Univerzitet u Novom Sadu, Centar za primenjenu statistiku, 17-29.

Seong, Y.C.; Jeong, J.S.; Park, G.K. 2012. The relation with width of fairway and marine traffic flow, *International Journal on Marine Navigation and Safety of Sea Transportation*, 6(3): 317-321.

Sulaiman, O.O.; Saharuddin, A.H.; Kader, A.S.A.; Laily, A.R.N. 2011. Safety and Environmental Risk and Reliability Model for Inland Waterway Collision Accident Frequency, *International Journal of Energy and Environment*, 5(4): 461-477.

Škurić, M.; Maraš, V. 2016. Determining the size of ferry fleet: Fuzzy logic approach, In *Maritime Technology and Engineering 3*, Guedes Soares & Santos (Eds), 2016, Taylor & Francis Group, London, 117-121,

Tan, B.; Otay, E.N. 1999. Modelling and analysis of vessel casualties resulting from tanker traffic through narrow waterways, *Naval Research Logistics*, 46(8): 871-892.

Цхадая, Н.Д.; Подосенова, Н.С. 2008. *Управление безопасностью труда*, ЦентрЛитНефтеГаз, Москва.

United States Coast Guard, USCG. 1999. Regulatory Assessment Use of Tugs to Protect Against Oil Spills in the Puget Sound Area, Report No. 9522-002, United States Coast Guard.

Zaman, M.B.; Santoso, A.; Kobayashi, E.; Wakabayashi, N.; Maimun, A. 2015. Formal Safety Assessment (FSA) for Analysis of Ship Collision Using AIS Data, *The International Journal on Marine Navigation and Safety of Sea Transportation*, 9(1): 67-72.

SESSION 6: MULTIMODAL TRANSPORTATION AND LOGISTICS RESEARCH

SELECTION OF THE INTERMODAL TRANSPORT CHAIN VARIANT USING AHP METHOD

Slobodan Zežević[1], Snežana Tadić[2], Mladen Krstić[3]
[1,2,3] University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia

Abstract: In the increasingly competitive world market freight transport faces demands for overcoming large distances while improving reliability and sustainability. Most of this transport is carried by road which generates various negative effects. On the other hand, intermodal transport allows the combination of different modes of transport, using the advantages of each of them. One of the problems in this area of research is the definition of the adequate transport modes and technologies combination, as well as the transport routes. Accordingly, the aim of this paper is to select the most favorable variant for the realization of the intermodal transport chain. As the decision-making process includes numerous conflicting criteria this is a problem of multi-criteria decision-making (MCDM) and must be accordingly addressed by the appropriate methods. The analytical hierarchy process (AHP) method is used in this paper and the applicability of the method for solving the defined problem is demonstrated by solving the case study of selecting the appropriate variant for the realization of the part of the intermodal transport chain from the port of Hamburg to trimodal terminal in Belgrade.

Keywords: intermodal transport chain, multi-criteria decision-making, AHP method.

1. Introduction

Increasing specialization and internationalization of the world trade leads to the increasing distances between suppliers, manufacturers and end users and the increase in the volume of world transport operations (OECD, 2010, UNCTAD, 2013). In the European Union, about 1,700 tons-kilometers of goods is transported in 2014, with the share of road transport of about 75% (Eurostat, 2015). A high share of road transport can be explained by the relative dense transport network that provides door-to-door transport and the high flexibility of route planning (Kummer, 2006). But the growing volume of road transport contributes to increasing road congestions, delays and other negative impacts on the reliability of transport (European Commission, 2012). In addition, transport is one of the main causes of harmful gases emission, noise and other negative impacts on the environment (European Commission, 2014). Consequently, companies are looking for alternative transport options that will enable them to reduce negative impacts of road transport and improve economic and environmental performance of their distribution systems (e.g. Demir et al., 2015). As a result, more and more researches are analyzing the negative impact of transport along the supply chain, with the aim of determining the consequences and ways to reduce them. The research results lead to the creation of policies that promote more intensive use of other modes of transport (rail, waterway) as well as the more intensive application of intermodal transport, which makes it possible to exploit the advantages of each mode of transport but also to eliminate their negative sides.

In the literature one can find different definitions or intermodal transport but the most widely accepted definition is that intermodal transport is movement of goods, in one and the same loading unit or a vehicle, by successive modes of transport without handling of the goods themselves when changing modes (ECMT, 1993). Various problems regarding intermodal transport are analyzed in the literature, such as the complementarities of different transport modes, changes in the price policy in intermodal systems, management of the flows between different modes of transport and their potential environmental impact, etc. (Sawadogo & Anciaux, 2010).

One of the problems faced by planners is to select the optimal route of goods transportation from the starting point (e.g. place of manufacture or supplier warehouse) to the endpoint (e.g. distribution center or retail warehouse). This is exactly the problem analyzed in this paper but in such a way to optimize the cost, time and performance while reducing environmental and social impacts. The aim is to support decision-makers (e.g. logistics operators) when selecting an appropriate route in the intermodal network, taking into consideration not only the criteria of time and costs, but also environmental and social criteria, and thus enabling them to choose the route, among the set of possible variants, that achieves a compromise between the benefits and negative impacts. As the achievement of this compromise implies consideration of different, mutually conflicting criteria, the problem is defined as a multi-criteria decision-making problem, and accordingly requires the application of appropriate method for its solution.

The paper is organized as follows. The second chapter describes in more detail the problem analyzed in this paper, i.e. the selection of the best variant for the realization of the part of the intermodal transport chain, as well as the criteria used in the decision making process. The third chapter describes the decision making method, AHP method, which is used for solving the case study. The fourth chapter describes the case study and presents the obtained results. Fifth chapter gives the concluding remarks.

2. Intermodal transport chain variant selection

When talking about transport chains optimization, most talk about the problems of finding the shortest or most economical route between the initial and final terminal, reducing transport costs while performing the delivery within a

[3] Corresponding author: m.krstic@sf.bg.ac.rs

reasonable period of time, reducing the cost of routing for each delivery in relation to the total cost of transport and inventories, finding the optimal mix of transport alternatives to reduce overall logistics costs, comparing different forms of transport and technologies in relation to the internal and external costs, etc. (Sawadogo & Anciaux, 2010). A special class of problems are the problems of selecting the routes in intermodal transport networks (e.g. Qu & Chen, 2008) and this is exactly the problem discussed in this paper. The aim is to choose the best variant of intermodal transport chain realization for a set of criteria. The problem is defined as the transport of intermodal transport units - Twenty-Feet Equivalent Units (TEUs), i.e. ***q*** pallets of goods (where q_u is the number of pallets in one TEU), along the road ***r***, from the starting point ***O*** to the end point ***D***. Every route ***r*** is the possible variant ***V*** and can be composed of multiple sections ***i (i=1,...,n)***. Each section represents part of the route with the length ***d***, while ***μ*** represents the number of vehicles of a certain transport mode ***m*** used for the transportation of goods. The selection of variant is based on the following criteria: transportation costs (C1), transportation time (C2), particle emissions (C3), noise emissions (C4), energy consumption (C5), traffic congestion (C6), transshipment time (C7), transshipment damages (C8) and accidents (C9), which are described in more detail below.

C1: Transportation costs. Transportation costs include fixed costs, fleet personnel costs and variable costs that depend on the traveled distance (fuels, tolls, etc.), and can be expressed by the following equation:

$$C1 = \sum_{i=1}^{n} \left[\left(c1_{im} + t_i c2_{im} + d_i c3_{im} \right) \mu_{im} \right] \tag{1}$$

where $c1_{im}$ denotes fixed costs of using transport mode *m*, $c2_{im}$ costs of hiring fleet personnel for the transport mode *m*, $c3_{im}$ costs of the distance traveled by the transport mode *m*, t_i transportation time on the section *i*, d_i length of the section *i*, and μ_{im} number of transport means *m* used on the section *i*.

C2: Transportation time. The criterion includes driving time and does not include time losses that may arise due to the border and customs control, traffic congestion, the regulations on the duration and the period of transport, etc. The transportation time is obtained by using the following equation:

$$C2 = \sum_{i=1}^{n} d_i / v_{im} * \mu_{im} \tag{2}$$

where v_{im} denotes the velocity of vehicles of the transport mode *m* on route section *i*.

C3: Particle emissions. The emission of harmful particles into the air by means of transport can be calculated using the following equation:

$$C3 = \sum_{i=1}^{n} \sum_{e=1}^{g} u * d_i * \rho_{iem} \tag{3}$$

where ρ_{iem} denotes the quantity of emitted harmful particles *e (e=1,...,g)* on route section *i* by the transport mode *m*.

C4: Noise emissions. Noise emission can be displayed using the following equation:

$$C4 = \sum_{i=1}^{n} u * d_i * \beta_{im} \tag{4}$$

where β_{im} denotes average costs of the noise emission for the transport mode *m*.

C5: Energy consumption. Energy consumption can be obtained by using the following equation:

$$C5 = \sum_{i=1}^{n} u * d_i * \varepsilon_{im} \tag{5}$$

where ε_{im} denotes the energy consumption of the transport mode *m*.

C6: Traffic congestion. Traffic congestion can be obtained by using the following equation:

$$C6 = \sum_{i=1}^{n} u * d_i * \chi_{im} \tag{6}$$

where χ_{im} denotes average costs of the traffic congestion for the transport mode *m*.

C7: Transshipment time. The transshipment time includes all times necessary for loading and unloading pallets to/from the transport unit and the times of transshipment TEU in breaking points, and can be obtained using the following equation:

$$C7 = u * \Delta_u * (2 + 2b_r) + q * \Delta_q \tag{7}$$

where Δ_u denotes average time for transshipment of one TEU, Δ_q average time for transshipment of one pallet, b_r number of breaking points on the route *r*.

C8: Transshipment damages. The cost of damaging the goods during transshipment can be obtained using the following equation:

$$C8 = u * \delta_u * p_u * (2 + 2b_r) + q * \delta_q * p_q \tag{8}$$

where δ_u denotes the average costs of damaging the goods during the transshipment of one TEU, δ_u average costs of damaging the goods during the transshipment of one pallet, p_u the probability of damaging the goods during the transshipment of one TEU, and p_q the probability of damaging the goods during the transshipment of one pallet.

C9: Accidents. Costs incurred as a result of an accident can be obtained using the following equation:

$$C9 = \sum_{i=1}^{n} u * d_i * \alpha_{im} \tag{9}$$

where α_{im} denotes average costs arising from accidents during transportation by the transport mode m.
For the calculation of the variants values in relation to the criteria, it is necessary to define the values of the parameters that appear in the previously defined equations (Table 1).

Table 1
Values of the parameters for the calculation of the variant values in relation to criteria

Parameter	Units	Road	Rail	Waterway
Capacity	TEU	2	120	180
c1	€	100	200	200
c2	€/h	20	26.27	26.27
c3	€/h	0.40	0.20	0.10
v_m	km/h	80	35-100	10
ρ_{CO2}	g/TEU.km	1,065	7.7	21.5
ρ_{Nox}	mg/TEU.km	8,130	0.8	24.8
ρ_{NMHC}	mg/TEU.km	570	0.55	25.22
$\rho_{part.}$	mg/TEU.km	195	13	25.71
β_m	€/TEU.km	0.112	0.484	0
ε_m	KJ/TEU.km	14,490	12.4	24.8
χ_m	€/TEU.km	0.083	0.003	0
Δ_u	h/TEU	0.3	0.3	0.3
Δ_q	h/pal	0.01	0.01	/
σ_u	1,000€/TEU	15	15	15
σ_q	1,000€/pal.	0.5	0.5	0.5
α_m	€/TEU.km	0.081	0.022	0
$p_{u,q}$	probability	variable	variable	variable

Source: Adapted from: European Commission – DG Mobility and Transport, 2014, Sawadogo & Anciaux, 2009.

The ultimate goal is to find a compromise solution for all the above criteria, which is why there is a need for the use of multi-criteria decision-making methods. For this purpose, AHP method, described in more detail bellow, is used in this paper.

3. AHP method

The multi-criteria decision-making problem described in this paper can be solved by using AHP method. AHP method developed by Saaty (1980) deals with the determination of the relative importance of criteria in multi-criteria decision-making problems. AHP method is based on three principles: the structure of the model, a comparative analysis of the structural elements (criteria and alternatives), and synthesis of priorities. The first step in applying the method is the formation of the hierarchical structure of the problem being solved. AHP first decompose a complex multi-criteria decision-making problem into a hierarchically arranged elements (objectives, criteria, alternatives). In general, according to the defined problem an analysis is performed to determine the relative weights of criteria at each hierarchical level and value of alternatives against the criteria. This analysis includes pair-wise comparison of all criteria in each hierarchical level as well as the pair-wise comparison of all alternatives against the criteria. The pair-wise comparison is performed by applying the standardized nine-point scale (Saaty scale) (Table 2).

Table 2
Saaty scale for criteria evaluation

Numerical value	Linguistic assessment
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6 i 8	Intermediate values

Steps of applying the AHP method are described below.
Step 1: Define the problem structure. First, it is necessary to define the elements of the structure, i.e. the objective, alternatives (variants) and the criteria for their prioritization.
Step 2: Form a matrix for pair wise comparison of the elements:

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1o} \\ a_{21} & a_{22} & \cdots & a_{2o} \\ \vdots & \vdots & \ddots & \vdots \\ a_{o1} & a_{o2} & \cdots & a_{oo} \end{bmatrix}, a_{kk}=1, a_{lk}=1/a_{kl}, a_{kl}\neq 0 \tag{10}$$

elements of which are a_{kl} $(k,l=1,2,...,o)$ and denote the importance of element *k* in relation to element *l*.
Step 3: Obtain the element weights based on the eigenvector. First, it is necessary to set up a matrix equation:

$$AW=\lambda_{\max}W \tag{11}$$

where W is the element weights matrix, and λ_{max} is the eigenvalue of the matrix *A*. Equation (11) becomes equation:

$$(A-\lambda_{\max}I)W=0 \tag{12}$$

where *I* is the identity matrix (matrix whose elements on the main diagonal have a value of 1).
λ_{max} is obtained by solving the equation:

$$\det(A-\lambda_{\max}I)=0\ . \tag{13}$$

Based on the value λ_{max} and by transforming the matrix equation (12), the system of linear equations is obtained. By solving this system of equations, while respecting the condition $\sum_{k=1}^{o} w_k = 1$, the values of the element weights w_k are obtained.
Step 4: Determine the consistency of the evaluations. In order to control the results of the method it is necessary to calculate the Consistency Ratio (*CR*) for each matrix and the overall inconsistency of the hierarchical structure. *CR* is calculated as follows (Saaty, 1996):

$$CR=CI/RI, \tag{14}$$

where *CI* denotes the Consistency Index and can be calculated as:

$$CI=\frac{\lambda_{\max}-n}{n-1} \tag{15}$$

RI denotes the Random Index values of which, for the matrix of different sizes, can be seen in the paper of Saaty (1996). *CR* is used for checking the consistency of pair wise comparisons and must be less than 0.10. Only then it can be said that the comparisons are acceptable.

4. Case study

In Serbia, in 2015, more than half a million tons of goods are imported from the countries of the Far East (National Statistics Institute). From the Far East ports, these goods are delivered in containers to the European ports, from where they are transported to Serbia. Most of the goods are coming into Europe via the northern-European ports, among which the port of Hamburg has a significant role in the realization of these flows. Port of Hamburg had in 2015 a turnover of 8.8 million TEUs, out of which over 50% was achieved with the Far Eastern ports (Port of Hamburg - statistics). Due to all the above, the objective of this paper is to analyse the part of the intermodal transport chain from the port of Hamburg in Germany to trimodal terminal (road, rail, river) in Belgrade, Serbia. For the realization of this transport chain, several variants are defined by combining available modes and different technologies of transport.
The problem includes the transport of 1,500t of goods, i.e. 3,000 pallets with the dimensions of 1,000x1,200 mm, whereby each pallet holds 500 kg of goods. 20 feet containers are filled with palletized goods in such a way that 100 containers are needed for transporting the entire quantity of goods, wherein each container holds 30 pallets. For the realization of the transport chain five variants (V) described below are defined (Figure 1).

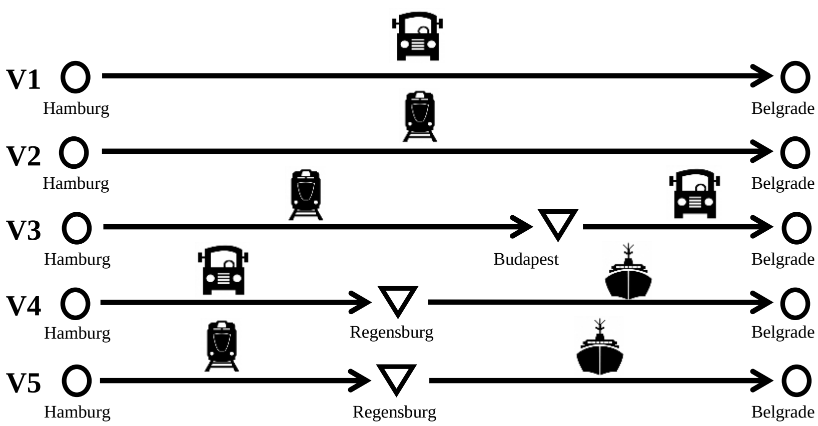


Fig. 1.
Transport chain variants

V1 – Direct road transport. The first variant includes a direct road transport of goods from the port of Hamburg to trimodal terminal in Belgrade. Goods packed in containers arrive to the port of Hamburg by ocean carriers. In the port of Hamburg containers are loaded onto the road transport vehicles that transport them to the Belgrade terminal. As the transportation from Hamburg to Belgrade is performed only by road transport, there are no breaking points. The goods are being unloaded from the containers in the terminal in Belgrade.
V2 – Direct railway transport. Second variant implies a direct rail transport from the port of Hamburg to the terminal in Belgrade. Similar to the variant 1, in the port of Hamburg containers are loaded onto railroad cars that transport them to Belgrade, without breaking points. Transport from Hamburg to Prague is performed through the part of the European rail freight corridor "North Sea-Baltic", then through the part of the corridor "Orient" from Prague to Budapest, and at last through B branch of the pan-European Corridor 10 from Budapest to Belgrade. The goods are being unloaded from the containers in the terminal in Belgrade.
V3 – Rail-road transport. The third option involves the transport of containers by using rail and road transport. Containers are loaded onto the railroad cars in Hamburg, and then transported from Hamburg to Budapest through the rail freight corridors "North Sea-Baltic" and "Orient". In Budapest, the change from rail to road transport mode occurs, since the section of the route from Budapest to Belgrade does not belong to the network of European rail freight corridors, therefore the costs are higher and speed considerably lower. The goods are being unloaded from the containers in the terminal in Belgrade.
V4 – Road-inland waterway transport. The fourth variant involves the transport of containers, loaded in Hamburg on the road freight vehicles, from the port of Hamburg to the port of Regensburg on the Danube. In the port of Regensburg, containers are being transshipped from road transport vehicles to the river barges, and then transported by Danube to the terminal in Belgrade. Containers are being transshipped and the goods unloaded from the containers in the terminal in Belgrade.
V5 – Rail-inland waterway transport. In the fifth variant, the containers are being loaded onto the railroad cars in the port of Hamburg and transported to the port of Regensburg. Between the ports of Hamburg and Regensburg there are regular lines of block trains, which transport 5 times a week. In the port of Regensburg, the containers are being transshipped from the railroad wagons onto the river barges and then transported by the Danube to the terminal in Belgrade, where the containers are being transshipped from the barges and the goods unloaded from the containers.
The distances traveled in each variant, by each mode of transport, as well as the total distances traveled are shown in Table 3.

Table 3
Distances traveled in each variant of the transport chain (km)

	Road	**Railway**	**Inland waterway**	**Total**
V1	1,534	/	/	1,534
V2	/	1,505	/	1,505
V3	380	1,185	/	1,565
V4	704	/	1,210	1,914
V5	/	750	1,210	1,960

First, it is necessary to define the hierarchical structure of the problem, which is shown in Figure 2.

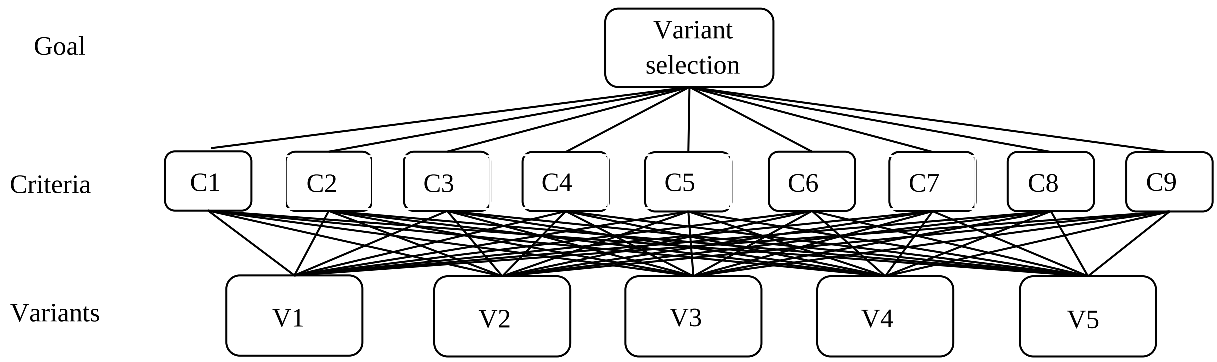


Fig. 2.
Hierarchical structure of the problem

Afterwards it is necessary to determine the criteria weights. By comparing the pairs of criteria in relation to the objective, ussing the Saaty scale given in Table 2, the resulting matrix A shown in Table 4 is obtained.

Table 4
Criteria pair wise comparison matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1.00	3.00	2.00	6.00	2.00	5.00	7.00	4.00	5.00
C2	0.33	1.00	0.50	4.00	0.50	3.00	5.00	2.00	3.00
C3	0.50	2.00	1.00	5.00	1.00	4.00	6.00	3.00	4.00
C4	0.17	0.25	0.20	1.00	0.20	0.50	2.00	0.33	0.50
C5	0.50	2.00	1.00	5.00	1.00	4.00	6.00	3.00	4.00
C6	0.20	0.33	0.25	2.00	0.25	1.00	3.00	0.50	1.00
C7	0.14	0.20	0.16	0.50	0.16	0.33	1.00	0.25	0.33
C8	0.25	0.50	0.33	3.00	0.33	2.00	4.00	1.00	2.00
C9	0.20	0.33	0.25	2.00	0.25	1.00	3.00	0.50	1.00

By solving the equation (13) for the given matrix the largest eigenvalue $\lambda_{max} = 9.205$ is obtained. Matrix equation (12) is then transformed into the system of linear equations, and by solving it the values of criteria weights *W=(0.277, 0.120, 0.184, 0.033, 0.184, 0.050, 0.023, 0.079, 0.050)* are obtained. By applying the equations (14) and (15) the value of CR=0.018 is obtained. As the values of CR is less than 0.10 it can be said that the evaluation is consistent.
After the criteria weights are obtained, the calculation of values of the variants in relation to criteria is performed by using the equations (1) – (9) and the parameters shown in Table 1. On the basis of these values, a comparison of all pairs of variants in relation to each criterion is performed by using the Saaty scale given in Table 2. Matrices obtained in this way are shown in Table 5.

Table 5
Matrices of pair wise comparisons of variants in relation to criteria

C1	V1	V2	V3	V4	V5
V1	1.00	0.17	0.25	0.33	0.20
V2	6.00	1.00	3.00	4.00	2.00
V3	4.00	0.33	1.00	2.00	0.50
V4	3.00	0.25	0.50	1.00	0.33
V5	5.00	0.50	2.00	3.00	1.00

C2	V1	V2	V3	V4	V5
V1	1.00	0.20	0.33	0.50	0.25
V2	5.00	1.00	3.00	4.00	2.00
V3	3.00	0.33	1.00	2.00	0.50
V4	2.00	0.25	0.50	1.00	0.33
V5	4.00	0.50	2.00	3.00	1.00

C3	V1	V2	V3	V4	V5
V1	1.00	0.14	0.17	0.20	0.14
V2	7.00	1.00	2.00	3.00	1.00
V3	6.00	0.50	1.00	2.00	0.50
V4	5.00	0.33	0.50	1.00	0.33
V5	7.00	1.00	2.00	3.00	1.00

C4	V1	V2	V3	V4	V5
V1	1.00	6.00	5.00	0.25	3.00
V2	0.17	1.00	0.50	0.11	0.25
V3	0.20	2.00	1.00	0.13	0.33
V4	4.00	9.00	8.00	1.00	6.00
V5	0.33	4.00	3.00	0.17	1.00

C5	V1	V2	V3	V4	V5
V1	1.00	0.20	0.25	0.33	0.20
V2	5.00	1.00	2.00	3.00	1.00
V3	4.00	0.50	1.00	2.00	0.50
V4	3.00	0.33	0.50	1.00	0.33
V5	5.00	1.00	2.00	3.00	1.00

C6	V1	V2	V3	V4	V5
V1	1.00	0.14	0.20	0.25	0.13
V2	7.00	1.00	3.00	4.00	0.50
V3	5.00	0.33	1.00	2.00	0.25
V4	4.00	0.25	0.50	1.00	0.20
V5	8.00	2.00	4.00	5.00	1.00

C7	V1	V2	V3	V4	V5
V1	1.00	1.00	2.00	2.00	2.00
V2	1.00	1.00	2.00	2.00	2.00
V3	0.50	0.50	1.00	1.00	1.00
V4	0.50	0.50	1.00	1.00	1.00
V5	0.50	0.50	1.00	1.00	1.00

C8	V1	V2	V3	V4	V5
V1	1.00	1.00	2.00	3.00	3.00
V2	1.00	1.00	2.00	3.00	3.00
V3	0.50	0.50	1.00	2.00	2.00
V4	0.33	0.33	0.50	1.00	1.00
V5	0.33	0.33	0.50	1.00	1.00

C9	V1	V2	V3	V4	V5
V1	1.00	0.25	0.33	0.33	0.17
V2	4.00	1.00	2.00	2.00	0.50
V3	3.00	0.50	1.00	1.00	0.33
V4	3.00	0.50	1.00	1.00	0.33
V5	6.00	2.00	3.00	3.00	1.00

By applying the equation (13) and by solving the system of equations obtained by transforming the equation (12) for each matrix in Table 5, the preference values of variants in relation to each criteria are obtained. These values, as well as the final weighted preference values of variants are shown in Table 6.

Table 6
Preference values of variants and final ranking

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	C9	Preference value	Rank
Weight	0.277	0.120	0.184	0.033	0.184	0.050	0.023	0.079	0.050		
V1	0.049	0.062	0.036	0.231	0.053	0.036	0.286	0.313	0.056	0.0809	5
V2	0.420	0.419	0.325	0.037	0.322	0.295	0.286	0.313	0.247	0.3453	1
V3	0.164	0.160	0.192	0.055	0.188	0.135	0.143	0.176	0.141	0.1674	3
V4	0.102	0.097	0.121	0.562	0.115	0.089	0.143	0.098	0.141	0.1244	4
V5	0.265	0.263	0.325	0.114	0.322	0.445	0.143	0.098	0.415	0.2818	2

Based on the results, it can be seen that the variant 2, which involves the railway transport of containers from the port of Hamburg to the trimodal terminal in Belgrade, proved to be the most favorable one in terms of the considered criteria. On the other hand, the least favorable variant is the variant of road transport of containers. In addition, all variants which included road transport were worse than the variants without the road transport, which confirms the thesis that (in terms of the considered criteria) it is more favorable to shift the goods flows from road to other modes of transport (railway and inland waterway) as much as possible.

5. Conclusion

In most developed countries, most of the freight transport is performed by road transport, while railway and inland waterway transport are either underutilized or very disorganized in terms of functioning and coordination with other modes of transport. Road freight transport recorded a steady increase in the past few decades. This has led to serious overload of road networks without significant improvement of existing infrastructure resulting in many negative effects such as higher external costs, traffic congestion, increased energy consumption, negative environmental impacts, etc.
These negative effects can be significantly mitigated through the efficient organization of intermodal transport system. Such systems can dramatically improve the utilization of transport resources and services, which leads to better planning and deliveries with lower logistics costs and higher levels of efficiency, and one of the ways to achieve these results is adequate planning of transport chains. The subject of this paper was the planning of one part of the transport chain, from Hamburg to Belgrade, i.e. the selection of the best variant of realization of the chain in relation to the defined criteria. As the problem involves consideration of a large number of criteria, it was necessary to apply a multi-criteria decision-making method for its solution, and accordingly in this paper the AHP method is used for this purpose. The results clearly show that minimization of the use of road transport, with greater use of other modes of transport (such as railway and inland waterway) lead to better results in terms of the considered criteria, whereby in the case considered in this paper, the variant that included the railway transport of containers is obtained as the best one.

References

Bayernhafen Regensburg - press release. Available from Internet: <http://www.donauhafen.de/presse/aktuelle-meldungen.html>

Demir, E.; Huang, Y.; Scholts, S.; Van Woensel, T. 2015. A selected review on the negative externalities of the freight transportation: modeling and pricing, *Transportation Research Part E: Logistics and Transportation Review*, 77: 95-114.

ECMT - European Conference of Ministers of Transport, 1993. Terminology on combined transport. Available from Internet: <ftp://ftp.cordis.europa.eu/pub/transport/docs/intermodal_freight_transport_ en.pdf>.

European Commission – DG Mobility and Transport, 2014. Update of the Handbook on External Costs of Transport - Final report.

European Commission, 2012. Measuring Road Congestion. Technical Report. European Commission.

Eurostat, 2013. Freight transport statistics. Available from Internet: <http://epp.eurostat.ec.europa.eu/ statistics_explained/index.php/ Freight_transport_statistics>.

Kummer, S. 2006. Einführung in die Verkehrswirtschaft. Vienna: Facultas.

OECD, 2010. Globalisation, transport and environment. Available from Internet: <http://www.oecd.org/greengrowth/ greening-transport/45095528>.

Port of Hamburg - statisics. Available from Internet: <https://www.hafen-hamburg.de/en/statistics>.

Qu, L.; Chen, Y. 2008. A Hybrid MCDM Method for Route Selection of Multimodal Transportation Network". *Part I, LNCS 5263*, 374-383.

Republički zavod za statistiku, Republika Srbija. Available from Internet: <http://webrzs.stat.gov.rs/WebSite/>.

Saaty, T.L. 1996. *The analytic network process*. Pittsburgh: RWS Publications.

Saaty, T.L. 1980. The Analytic Hierarchy Process. New York, NY: McGraw-Hill International.

Sawadogo, M.; Anciaux, D. 2009. Intermodal transportation within the green supply chain: An approach based on the ELECTRE method, *Computers & Industrial Engineering (CIE)*. International Conference on Industrial Engineering, 6-9 July 2009, 839-844.

Sawadogo, M.; Anciaux, D. 2010. Reducing the environmental impacts of intermodal transportation: a multi-criteria analysis based on ELECTRE and AHP methods. In *Proceedings of the 3rd International Conference on Information Systems, Logistics and Supply Chain Creating value through green supply chains ILS 2010 – Casablanca (Morocco), April 14-16.*

UNCTAD, 2013. Review of Maritime Transport. United Nations. Available from Internet: <http://unctad.org/en/ publicationslibrary/ rmt2013_en.pdf>.

TERMINAL FOR CUSTOMER-FRIENDLY LOGISTICS SERVICES

Petra Matzenberger[1], Volker Hartl-Benz[2], Bernhard Rüger[3]
[1,2,3] *Vienna University of Technology, Institute of Transportation, Research Centre of Railway Engineering, Traffic Economics and Ropeways, Austria*

Abstract: The transport of small freight (general cargo, baggage and packages) is definitely increasing at the moment. This is supported by online commerce. Current delivery services are inflexible concerning customers' needs and demands. For example the person's physical presence is necessary at the delivery address to accept it or the person has to pick up the package in a shop. Moreover, delivery services were often uneconomic because they needed several delivery attempts. This was the reason for the exploratory project smartBOX. The intention of smartBOX (founded by the Austrian Ministry for Transport, Innovation and Technology and the Austrian Research Promotion Agency) was to combine increasing mobility requirements and tightening resources by creating an intelligent and holistic approach. Visionary mechanisms of autonomous traffic optimisation together with cross-sectoral transport and service models as well as the development of terminals and intelligent containers and transport, information and communication technologies could help managing the challenges of small freight mobility in urban areas, increasing quality of life and saving the environment. In order to minimise the development risks it was first necessary to survey and define all requirements. Therefore, extensive customer surveys were conducted.

Keywords: logistics services, terminal, box, freight mobility, package, luggage.

1. Introduction

The transport of small freight (general cargo, baggage and packages) is definitely increasing at the moment. In fact, this market has been the fastest-growing transportation segment in the United States over the past two decades. For the parcel delivery industry it is typical that they are multimodal. They use small trucks, cars or messengers for pickup and delivery and another mode of transport such as a truck, the railway or planes for the line-haul. (William, 2009)
Actual trends of the small freight logistic show that the delivery sizes are getting smaller and more fragmented concerning the B2B-sector (Business to Business) and the number of single deliveries and home deliveries is increasing concerning the B2C-sector (Business to Costumer). Reasons for these trends are internet-shopping in the B2C-sector and the electronic-sourcing in the B2B-sector. Moreover, often there is more than one delivery attempt in the B2C-sector.
The big problem in the small freight mobility is the last mile, especially in city centers. The cost of the last mile is 45% in arithmetic average. It ranges from 20% to 60% depending on the company (Grün & Gudehus, 2003). Typical problems of the delivery in the city centre are the parking situation, the traffic, one-way streets and pedestrian areas. Concerning the parking situation especially in shopping streets and also in housing areas there are no free parking areas for the delivery service and so the car has to park in a second line. Sometimes this is tolerated, but sometimes the delivery service has to pay penalties for wrong parking. Concerning pedestrian areas the delivery services have to take care of the time slot for delivery. (Bogdanski, 2014)

1.1. Main idea of the project

The aim of the following project is to reduce traffic density by using a prospectively integrated system for autonomous general cargo and luggage and package transport. Simultaneously promoting public passenger traffic by developing a system for public freight traffic. Passengers will be getting rid of their luggage and passenger traffic and freight mobility are going to be installed at the same time. As a result the quality of life will increase and the environment will be perserved. In order to realise these goals, the research project smartBOX will provide concepts regarding the following system components:

- Conception of a standardised container with an intelligent control system and user security access (=the "smartBOX").
- Development of a pool system in order to provide availability, exploitation and control of the smartBOX regarding B2B as well as private passenger traffic by using electronic tracking&tracing methods and web-based communication technologies.
- Conception of extensively used vandalism proof pick-up and dropping terminals in public areas, as well as housing complexes. Adaption for freight transfer in the B2B sector.
- Conception of an encroached, intermodal transport system which will realise and bundle transport requirements in order to prevent multiple trips.
- Conception of IT-functionality by considering transparency and data privacy for decentralised autonomous subsystems.
- Conception of business models to provide favourable and distance-related transportation rates, cover service-provider expenses and combination with presently used systems.

[1] Corresponding author: petra.matzenberger@tuwien.ac.at

1.2. Statement of purpose

The main topic of this paper is the terminal. We found out that customers would be most satisfied if the luggage service is near one's residence. Best option to fulfil this demand would be a terminal. On the one hand, this terminal could be near one's residence door, but on the other hand it could also be at a train station instead of the current luggage deposits. An aim of the project "smartBOX" was to find out what a terminal should include and look like for the customer. Moreover, a test was conducted with customers with different kinds of luggage and different heights. The conclusion was that the optimal height of a lockbox for the terminal in this case depends on the luggage. By the way, most of this paper is based on the internal project results of the project "Smartbox" and a project called "Store and Go+".

2. Method

The method to get a good view of potential customer's needs and demands was a survey in form of a questionnaire. For that reason people on the street in Vienna and Parndorf, a shopping area in Lower Austria, and in four post offices, in Vienna and Lower Austria, were interviewed during January and April 2015. There was also an online questionnaire.
The first part of the questionnaire included questions concerning demographic information and the persons' residences. Moreover, the participants were asked about the actual delivery services. The next part included general questions about the terminal and its design. The last part of the questionnaire included questions about a pickup and delivery station.
With the help of the results of the surveys, it was possible to get detailed information about the interest groups for the terminal and the logistics services as well as their needs and demands. Additionally, qualitative surveys were done with business proprietors to determine their interest in and demands for a terminal and the developed logistics services of the smartBOX concept. They also showed an interest in the service, especially to oppose the online trade. The results of the surveys provide a basis for the design of the whole system and for the evaluation of the new and operating systems.
This paper only includes the results of the survey concerning the terminal.

3. Results

3.1. General data

Altogether, 890 persons were questioned on the street in Vienna and Parndorf, a shopping area in Lower Austria, and in four post offices, in Vienna and Lower Austria. Most of them (80%) were between 18 and 59 years of age. The age group between 18 and 26 made up with 28% of all questioned persons the largest group. Concerning the gender, more male persons participated in the survey (57%). The most of the questioned persons were living in a city. Below is some more detailed information about main residence.

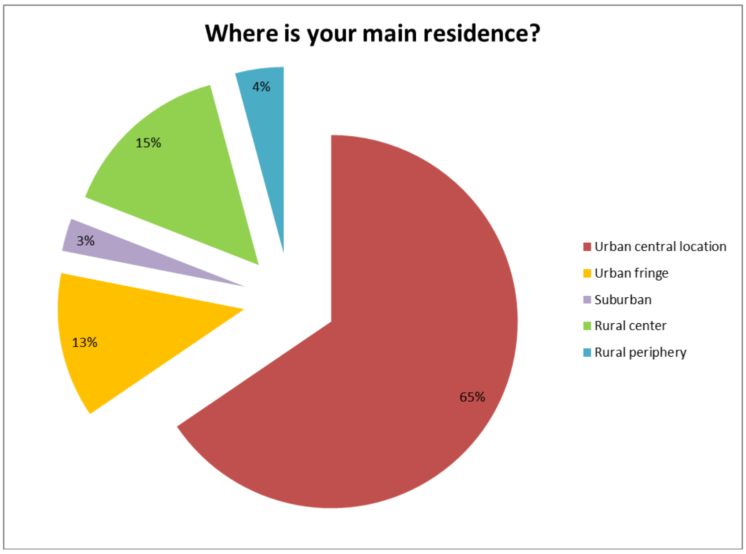


Fig. 1.
Representation of the main residences

42 % of the questioned persons were living in a flat with more than ten housing units and 24% in a flat with a maximum of ten housing units, 8% in a multi-family house and 26% in a one-family house.
In addition, the persons were questioned if there was normally someone at home during the day to accept a delivery. This question was answered with "yes" by 32% of the questioned persons, with "likely yes" by 15%, with "likely no" by 17% and with "no" by 36%.

3.2. Interest in the terminal

To find out the interest of the persons in a terminal to receive packages and also luggage, they were asked what their maximum effort would be to reach such a terminal. This interest is shown in Figure 2.

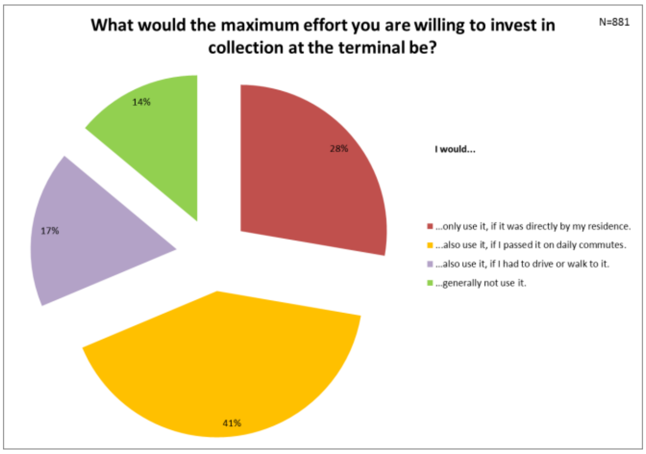


Fig. 2.
Representation of the interest in the developed logistics services

In addition, the interest in the developed logistics services of different groups was analysed. The results showed that older people were less interested in the new logistics services. Especially interested were persons, where no one is at the residences during the day (89%). Persons, who are satisfied with the actual situation, would use the terminal (23%) less than persons who are unsatisfied. Persons who never had problems with the actual service would use the terminal less (30%).
Concerning the setting of the principal residence people living outside a city centre or outside a village would render more to reach a terminal and use the logistics services (compare Fig. 3).

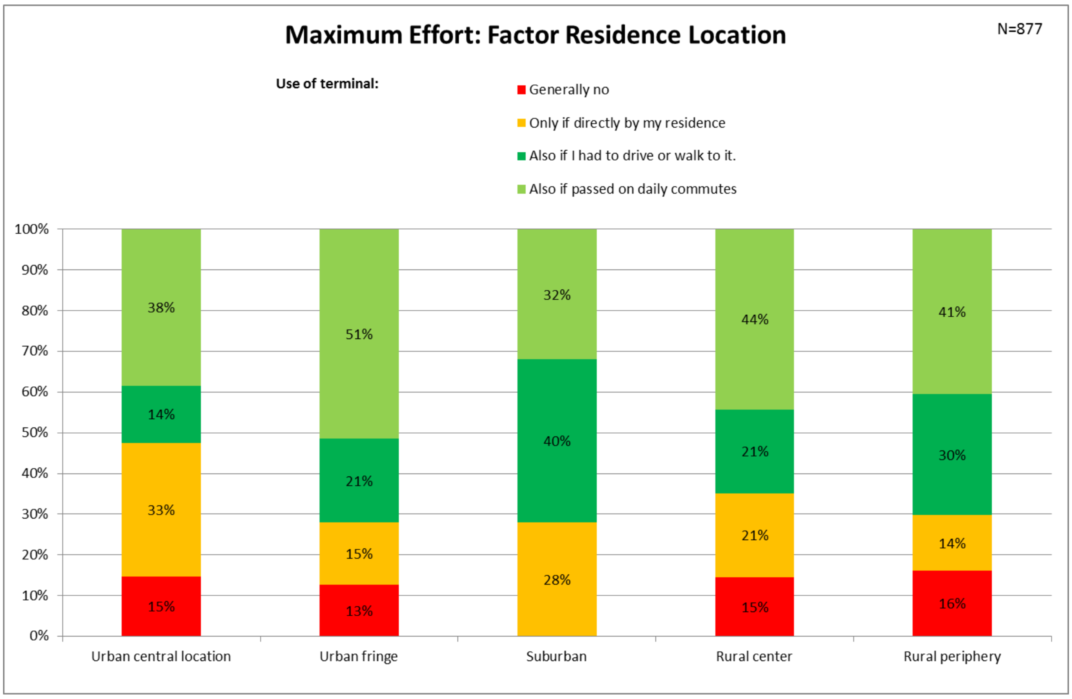


Fig. 3.
Representation of the interest in the developed logistics services of different settings of the principal residence

The survey showed that there were not many people who wouldn't generally use the developed logistics services. Counter-arguments for the terminal were:

- They prefered human contact.
- They were afraid that there are less jobs.
- It is too complex.
- The post office is next door.
- They are satisfied with the actual service.

Persons who were interested in the terminal were asked about the design of the terminal and how much time they would spend as a maximum. 35% of the questioned persons said, that they would maximally spend five minutes. 52% would spend 15 minutes and 11% 30 minutes. Only 2% would spent more that 30 minutes.

3.3. The design of the smart terminal

The questioned persons were asked what the terminal should look like in regard to different facilities. In general, following results, ordered by importance were shown:

1. **All parcel services (e.g. Post, DHL, DPD,…) should deliver to the terminal.**
   97% of the questioned persons thought that this is important or very important.
2. **24h-accessibility**.
   This was important or very important for 90%. It was less important for older people or for people, who are satisfied with the current situation.
3. **Good accessibility by public transport.**
   82% of the questioned persons said that this is important or very important. It was even more important for women.
4. **Roofing of the terminal.**
   This was important or very important for 74%. The interest was increasing with age.
5. **Well frequented, lively area.**
   66% thought that this is important or very important for the terminal's setting. Especially women and persons who were living in the city centre preferred such a setting. Interestingly persons who were living outside a village showed an interest in having the terminal in a busy neighbourhood.
6. **Free parking areas directly at the terminal.**
   This was important or very important for 59%. It was more important for men. Moreover, the interest is increasing with the age. The free parking areas were more important for people on the countryside or outside the city centre.
7. **The terminal should be inside a building.**
   This was important or very important for only 44%. The interest was increasing with age.

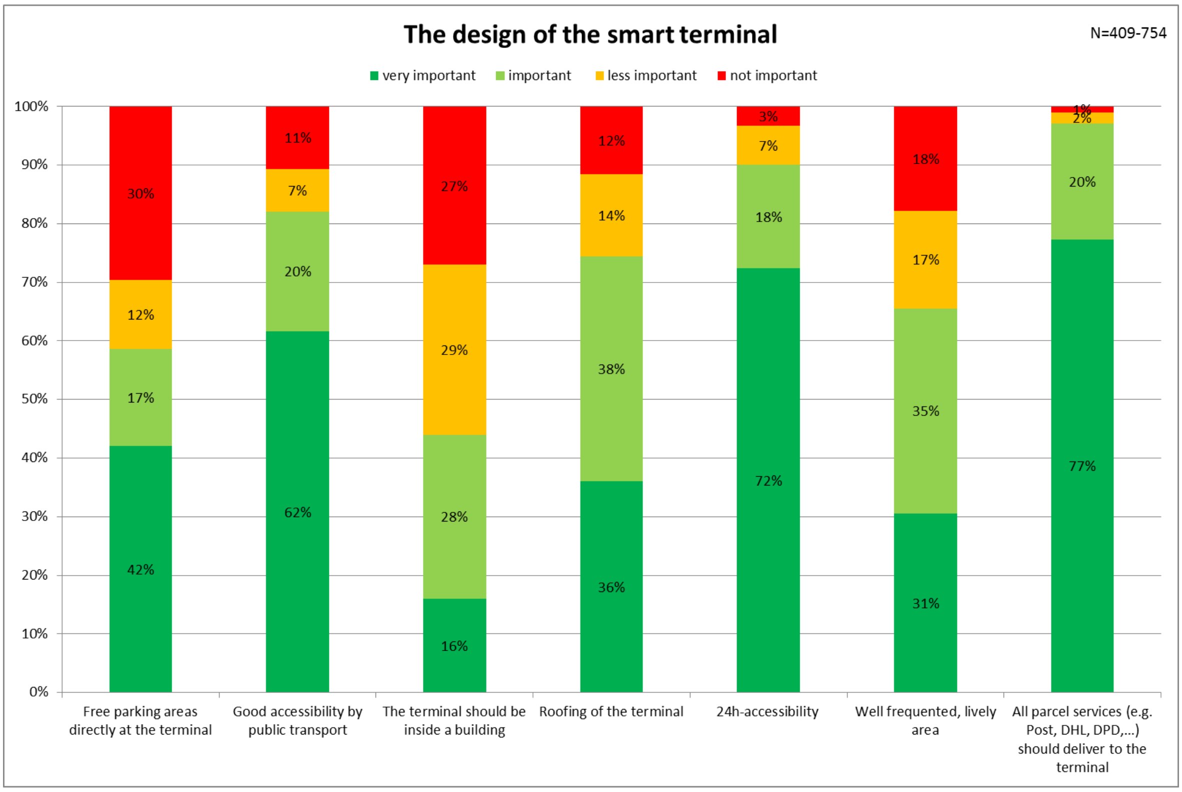


Fig. 4.
Representation of certain design aspects of the smart terminal

In addition, the people were questioned on how they would like to be informed if their package or parcels had arrived in the terminal. The most interesting notification options were SMS (84%) and mail (55%).
On a side note, 48% of the questioned people would pay extra for using the terminal. For 86% a registration at the provider would be no problem. 89% would welcome video control of the terminal.

3.4. Health related demands concerning lifting something

An essential aspect concerning health and ergonomics is the height of the terminal and the lifting process of the box. On the one hand, the terminal should be ergonomic for the customer and, on the other hand, also for the parcel service provider.
In another project of the Insitute of Transportation of the Vienna University of Technology it was evaluated what the optimal height and shape were to store packages. These results could be implemented in the developed logistics services because lifting a box like the smartBOX would be a similar process.
Concerning the results of the old project they agreed, in principle, with the idea that the preferred height is dependent on the transport method. That means that a trolley that rolls on the floor was best stored near the floor at the terminal. If someone is carrying his/her suitcase they preferred to store it in a height of 60 cm. The following figure shows the preferred storing height of different objects. There were two different shapes of the place where the object was stored.

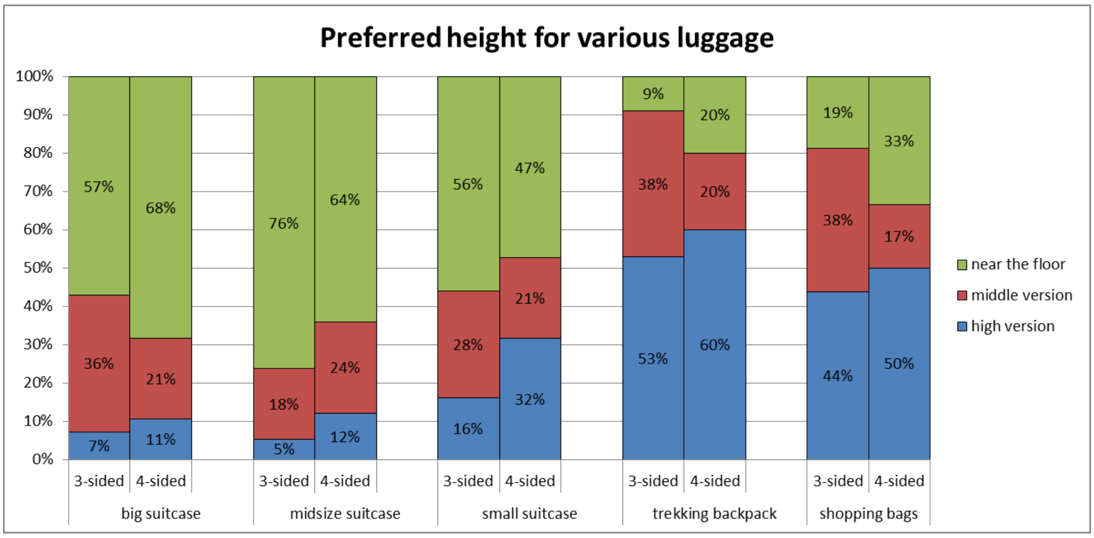


Fig. 4.
Preferred storing height of different objects

Summing up the results of the pioneered project the preferred height is dependent on the object and how it is transported. For example, if it is possible that the box is rolling on the floor, the preferred height would be near the floor. Surely, the weight of the object is an important factor. But no one would transport a one kilogram box on the floor. Therefore, the look and layout of the terminal is an influencing factor.

4. Discussion and Conclusion

Altogether 86% of the questioned persons would use the developed logistics services. This result shows that there is a great interest for such a logistics service. Also important to remark: Older persons (over 75 years) had a lower interest and are more satisfied with the actual situation than younger ones.
The customers have the following demands concerning the developed logistics services:

- The customers at least had to cross the station on their daily routes.
- A terminal should be reachable in 15 minutes (both ways combined).
- All service providers should be able to deliver to this terminal.
- In the city it is important that the station is easily reachable by public transport.
- On the countryside a free parking area is important.
- For the most the terminal should have roofing.
- The terminal should be in a lively, well frequented area, especially for women.
- A notification should be sent by mail or short message if the parcel was delivered.
- There should be no extra-costs for the service.
- People would pay extra for a longer storage at the terminal.
- A registration free of charge and a video control would be no problem for the customers.

Concerning the opinion of the commercial partners, there was an interest for the developed logistics services. For them the most important point is that the service has to be uncomplicated, safe and quick. If the service would comply with these points, the commercial partners would even support the service financially.

Acknowledgements

The authors acknowledge the Federal Ministry for Transport, Innovation and Technology and the Austrian Research Promotion Agency for funding and supporting this project.

References

Bogdanski, R. 2014. *Nachhaltige Stadtlogistik durch Kurier-, Express-, Paketdienste*. Bundesverband Paket & Express Logistik BIEK, Berlin.

Grün, O.; Gudehus, T. 2003. *Innovative Lösungen für die letzte Meile. Jahrbuch der Logistik*. free beratung Gesellschaft für Kommunikation im Marketing mbH, Frankfurt am Main.

Rueger, B. et al. 2011. Store and Go+ 2011. Available from Internet: <http://www.netwiss.at/294620/store-go>.

Rueger, B. et al. 2016. SmartBOX. Available from Internet: <http://www.netwiss.at/2161320/smartBOX>.

William T.D. 2009. *Parcel and small Package Delivery Industry*. Create Space, North Charleston.

SAFETY OF NAVIGATION - COMPARATIVE ANALYSIS OF THE STATISTICAL INSPECTION REPORTS OF CROATIA'S HARBOUR MASTER OFFICE ZADAR OVER THE PAST TWO YEARS

Tatjana Stanivuk[1], Pero Vidan[2], Frane Prolić[3]
[1,2] University of Split, Faculty of Maritime Studies, Ruđera Boškovića 37, 21000 Split, Croatia
[3] University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Ruđera Boškovića 32, 21000 Split, Croatia

Abstract: This paper outlines and analyses the annual statistical report on the performance of Croatia's Harbour Master's Office in Zadar and its Branch Offices. Statistical data have been processed with regard to the number of employees, number of registered ships, boats and yachts, as well as with reference to the cargo and passenger traffic through the ports under the jurisdiction of the Harbour Master's Office in Zadar, and number of search and rescue operations aimed at saving life and property at sea. A statistical analysis of the inspections carried out in 2015 has also been made. Statistical data for the year of 2015 have been compared with the 2014 data in order to achieve a better insight into the overall performance of the Zadar Harbour Master's Office and its Branch Offices.

Keywords: domestic and foreign ships, boats and yachts, statistical analysis of data, harbour master's office, branch offices, inspection and survey.

1. Introduction

Croatia is a maritime country with a very indented coastline and dense sea traffic. In addition to other issues, the Ministry of Maritime Affairs, Transport and Infrastructure of the Republic of Croatia is in charge of management and control of maritime demesne, seaports and vessels.
The Harbour Master's Office in Zadar, like all other Harbour Master's Offices in Croatia, operates under the jurisdiction of the Ministry of Maritime Affairs, Transport and Infrastructure. The Office consists of two main departments: the inspection department and the department for maritime traffic and search and rescue operations. This paper provides a statistical insight into the performance and efficiency of the two departments of the Zadar Harbour Master's Office and its Branch Offices.
The Zadar Harbour Master's Office includes 9 harbour branch offices whose authorised personnel carry out inspections of domestic and foreign vessels, both in ports and at sea, and keep records on the type, extent and nature of detected deficiencies. All these data are entered into the central computer system at the Ministry of Maritime Affairs, Transport and Infrastructure. The system stores information on all inspected ships, boats and yachts in the Republic of Croatia. Owing to the availability and transparency of the data which can be searched and selected through the categories of individual vessels or authorised employees, it is not difficult to make a statistical analysis and annual reports on the number of performed inspections, type and extent of detected deficiencies, number of detentions, number of search and rescue (SAR) operations, overall movement of cargo and passengers through the ports of the Republic of Croatia, etc. Supported by these information systems, the Ministry of Maritime Affairs, Transport and Infrastructure itself creates annual and other reports.
When inspecting foreign vessels, the inspectors in charge of the safety of navigation act exclusively in compliance with the international conventions and IMO (International Maritime Organisation) regulations governing the safety of navigation, safety of life at sea, environment protection, such as SOLAS, MARPOL, LOAD LINE conventions, etc. (Maritime Code, 2004; Maritime Code, 2007; Maritime Code, 2008; Maritime Code, 2011; Maritime Code, 2013)
When inspecting domestic ships, boats and yachts, vessels, the inspectors in charge of the safety of navigation act in line with the national laws and regulations such as Maritime Code, Maritime Demesne and Seaports Act, Regulation on the Inspection of the Safety of Navigation, Port Order Regulations, etc. (Maritime Code, 2004; Maritime Code, 2007; Maritime Code, 2008; Maritime Code, 2011; Maritime Code, 2013; Maritime Demesne and Seaports Act 2003; Maritime Demesne and Seaports Act, 2006; Maritime Demesne and Seaports Act, 2009)

2. Structure of the Zadar Harbour Master's Office

The Zadar Harbour Master's Office consists of the central office and nine branch offices distributed across the Zadar County, along the coast (Biograd na moru, Novigrad, Starigrad) and on larger islands: in the town of Pag on Pag Island, Preko on Ugljan Island, Sali and Božava on Dugi Otok, and on the islands of Ist and Silba. (Ministry of Maritime Affairs, Transport and Infrastructure - official web-site).

[1] Corresponding author: tstanivu@pfst.hr

Table 1
General data about the Harbour Master's Office in Zadar and the respective Branch Offices for 2015, compared to 2014

TYPE OF DATA	HARBOUR MASTER'S OFFICE AND HARBOUR BRANCH OFFICES										TOTAL	INDEX	TOTAL
	ZADAR	BIOGRAD n/m	NOVIGRAD	STARIGRAD	PAG	PREKO	SALI	BOŽAVA	IST	SILBA	2015		2014
Sea surface under jurisdiction of the Harbour Office in NM	**103,0**	**68,0**	**38**	**27**	**63**	**58,0**	**57,0**	**70,0**	**40,0**	**48,0**	**572,0**	**100,00**	**572,0**
Number of employees on 31 December 2015	**23**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**29**	**96,67**	**30**
Number of inspectors	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**100,00**	**4**
Number of authorised state officers	**8**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**14**	**93,33**	**15**
Number of part-time employees	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**42,86**	**7**
Vacant jobs	**10**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**14**	**140,00**	**10**

Source: Authors

The sea surface of the Zadar County covers a total of 572 NM (Table 1). Each office, including the central Harbour Master's Office and individual Branch Offices, covers a part of the area, as defined by the Law on Harbour Master's Offices. In addition to the jurisdiction area, Table 1 shows the number of employees for each branch office respectively, as well as the number of inspectors, authorised state officers, part-tome employees and vacancies with regard to the optimum number of staff as defined by the regulations. The Table clearly shows the difference in number of employees for the years 2014 and 2015 at all branch offices of the Zadar Harbour Master's Office, especially regarding the number of part-time workers whose number decreased in 2015, resulting in the corresponding number of vacant jobs.

The inspectors of the safety of navigation are entitled to carry out surveys and inspections of all vessels, whereas the authorised specialists are under the department for maritime traffic and search and rescue operations and are exclusively authorised for inspecting boats and yachts, both domestic and foreign. (Stanivuk et al., 2015)

Here it is necessary to point out that, besides the inspection of vessels, the department for maritime traffic of the Harbour Master's Office in Zadar is also in charge of other operations, such as search and rescue, signing on and signing off of the seafarers, maritime traffic control, etc.

3. Comparative method of statistical analysis of vessels in the area of Zadar Harbour Master's Office in 2015, compared to 2014

Table 2 provides the list of all vessels entered in the Register of shipping in the area of Harbour Master’s Office of Zadar by the end of 2015, compared with the year of 2014.

Table 2
List of ships and yachts entered in the Register of shipping of the Zadar Harbour Master's Office by vessel type, registered by the end of 2015, compared to 2014

TYPE OF DATA	HARBOUR MASTER'S OFFICE AND HARBOUR BRANCH OFFICES										TOTAL	INDEX	TOTAL
	ZADAR	BIOGRAD n/m	NOVIGRAD	STARIGRAD	PAG	PREKO	SALI	BOŽAVA	IST	SILBA	2015		2014
Total registered vessels	**294**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**294**	***100,34***	**293**
Merchant ships	***162***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	**162**	***100,00***	***162***
Cargo	91	0	0	0	0	0	0	0	0	0	91	*100,00*	91
Passenger	71	0	0	0	0	0	0	0	0	0	71	*100,00*	71
Fishing vessels	***132***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	**132**	***100,76***	***131***
Trawlers	48	0	0	0	0	0	0	0	0	0	48	*100,00*	48
Seiners	84	0	0	0	0	0	0	0	0	0	84	*101,20*	83
Other	0	0	0	0	0	0	0	0	0	0	0	-	0
Number of vessels under construction	***2***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***2***	***100,00***	***2***
Number of newly registered vessels	***6***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***6***	***60,00***	***10***
Number of deregistered vessels	***5***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***5***	***55,56***	***9***
Total registered yachts	**642**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**642**	**127,89**	**502**
Yachts for commercial purpose	***469***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***469***	***100,21***	***468***
Yachts for personal purpose	***173***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***173***	***508,82***	***34***
Number of newly registered yachts	***170***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***170***	***361,70***	***47***
Number of deregistered yachts	***30***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***30***	***120,00***	***25***

Source: Authors

The above Table 2 clearly shows that the Register of ships and yachts is under exclusive jurisdiction of the Harbour Master's Office in Zadar, whereas the Branch Offices are authorised only for the registration of boats.
With regard to the registered vessels in the years of 2014 and 2015, their number remained unchanged or was just slightly changed in most categories. However, the newly registered vessels saw a 60% drop, while the number of deregistered vessels decreased by 55.56%. These figures resulted from the fact that a large number of fishing vessels were already in exploitation in 2015 while some merchant ships, e.g. owned by the shipper Tankerska plovidba Zadar, were sold or deregistered due to their age and the global recession.
On the other hand, the number of newly registered yachts considerably increased from 2014 to 2015. The sharp rise of 361.7% resulted from Croatia's accession to the European Union, as the EU citizens were now able to enter their yachts in the Register of yachts of the Republic of Croatia under more favourable financial terms. As expected, most of the newly registered yachts have been used for personal non-commercial purposes.

Table 3
List of boats entered in the Register of shipping of the Zadar Harbour Master's Office by vessel type, registered by the end of 2015, compared to 2014

TYPE OF DATA	HARBOUR MASTER'S OFFICE AND HARBOUR BRANCH OFFICES										TOTAL	INDEX	TOTAL
	ZADAR	BIOGRAD n/m	NOVIGRAD	STARIGRAD	PAG	PREKO	SALI	BOŽAVA	IST	SILBA	2015		2014
Total registered boats	**9.543**	**4.541**	**1.269**	**1.560**	**2.092**	**2.445**	**769**	**479**	**370**	**630**	**23.698**	***104,32***	**22.717**
Boats for commercial purposes	***1.470***	***884***	***82***	***225***	***143***	***555***	***83***	***59***	***30***	***26***	**3.557**	***101,34***	***3.510***
Cargo transport	5	2	0		13	1	5	0	3	0	29	193,33	15
Passenger transport	1.194	766	5	13	76	44	47	6	1	2	2.154	*103,86*	2.074
Fishing boats	271	114	77	212	54	510	31	18	26	24	1.337	94,22	1.419
Trawlers	*17*	*10*	*1*	*10*	*0*	*0*	*1*	*0*	*0*	*0*	*39*	*72,22*	*54*
Seiners	*10*	*2*	*4*	*1*	*0*	*0*	*0*	*0*	*0*	*0*	*17*	*94,44*	*18*
Other	*244*	*102*	*72*	*201*	*54*	*555*	*30*	*18*	*26*	*24*	*1.326*	*98,44*	*1.347*
Boats in public service	***25***	***2***	***0***		***0***	***0***	***0***	***1***	***0***	***0***	**28**	***103,70***	***27***
Boats for personal purposes	***8.048***	***3.655***	***1.187***	***1.364***	***1.926***	**1.890**	***686***	***419***	***340***	***604***	**20.119**	***104,90***	***19.180***
Number of newly registered boats	*911*	*250*	*20*	*107*	*92*	*114*	*15*	*11*	*7*	*24*	*1.551*	*158,59*	*978*
Number of seregistered boats	*190*	*112*	*9*	*93*	*70*	*30*	*22*	*3*	*6*	*36*	*571*	*106,73*	*535*

Source: Authors

Table 3 presents the statistical values referring to the number of boats registered by 31 December 2015, compared to their number on 31 December 2014, for each boat category and for each organisational unit of the Zadar Harbour Master's Office, including the main and branch offices. The presented figures indicate an increase in total registered boats in 2015, as compared with 2014. The sharpest rise (58.6%) was experienced in the category of the newly registered boats, while the number of fishing boats (i.e. trawlers) plummeted by 27.7% (Tomašević at al., 2007).

As expected, the largest growth in the number of newly registered boats was experienced in the Harbour Master's Office in Zadar, given the fact that the city is home to three large marinas (Tankerkomerc, Borik and Sports port Uskok), as well as the nearby marina Dalmacija, Croatia's largest marina.

Apart from Zadar, a significant growth of the newly registered boats was experienced in the Branch Offices of Biograd, Preko and Pag, due to trends in nautical tourism and the marinas situated in the Branch Offices' respective areas: marinas Ilirija, Kornati and Šangulin in Biograd area, marinas Olive Island and Preko in Preko area, and marina Šimuni in Pag area.

There was only slight oscillation in the total number of boats registered in 2015 and 2014, i.e. this value remained constant.

4. Statistical overview of the movement of domestic and foreign vessels, passengers and cargo in the ports under jurisdiction of the Zadar Harbour Master's Office in 2015, compared to 2014

Table 4 presents the overall traffic of domestic and foreign vessels. In the ports under the jurisdiction of the Harbour Master's Office of Zadar, there was a decrease in traffic of domestic vessels and an increase in traffic of foreign vessels in the year of 2015, compared to 2014 (Stanivuk et al., 2015).

Table 4
Statistical overview of the movement of domestic and foreign vessels, passengers and cargo in the ports under the jurisdiction of the Zadar Harbour Master's Office for the year of 2015, compared to 2014

TYPE OF DATA	HARBOUR MASTER'S OFFICE AND HARBOUR BRANCH OFFICES										TOTAL	INDEX	TOTAL
	ZADAR	BIOGRAD n/m	NOVIGRAD	STARIGRAD	PAG	PREKO	SALI	BOŽAVA	IST	SILBA	2015		2014
Arrivals of domestic vessels	11.594	11.311	0	2	0	5.075	1.560	1.263	0	2.372	33.177	96,25	34.469
Arrivals of foreign vessels	168	3	0	0	0	8	14	0	0	0	194	155,20	125
Departures of domestic vessels	11.742	11.321	0	2	0	5.029	1.567	1.240	0	2.505	33.406	96,22	34.718
Departures of foreign vessels	168	1	0	0	0	7	14	0	0	1	191	140,44	136
Individual vessels in internatio-nal traffic	119	0	0	0	0	6	8	0	0	0	133	241,82	55
Cargo loaded in tons	164.236	11.815	0	0	0	26.613	0	1.111	0	0	203.775	114,29	178.292
Passengers embarked	1.124.658	460.102	0	31	0	715.956	63.781	82.863	10.499	54.708	2.512.598	97,61	2.574.140
Vehicles loaded	153.665	92.463	0	0	0	115.629	0	25.075	290	519	387.641	99,42	389.894

Source: Authors

It should be also pointed out that, compared to the year of 2014, there was a drop in the overall traffic of passengers and vehicles in the RO-RO (passenger) trade in 2015, whereas the same period saw a 12.5% (25,000 tons) increase in loaded cargo movement.

5. Inspections at the Harbour Master's Office in Zadar and its Harbour Branches in 2015, compared to 2014

This section provides a detailed analysis of the activities performed by the safety of navigation inspectors at the Harbour Master's Office in Zadar and the authorised specialists at the Branch Offices (http://www.mppi.hr/default.aspx?id=7397, 2016).

Table 5
Inspections performed by the Harbour Master's Office in Zadar and its Branch Offices in 2015, compared to 2014

TYPE OF DATA	HARBOUR MASTER'S OFFICE AND HARBOUR BRANCH OFFICES										TOTAL	INDEX	TOTAL
	ZADAR	BIOGRAD n/m	NOVIGRAD	STARIGRAD	PAG	PREKO	SALI	BOŽAVA	IST	SILBA	2015		2014
Total number of the addressed issues	**815**	**88**	**0**	**144**	**0**	**0**	**258**	**134**	**0**	**82**	**1.521**	***80,01***	**1.901**
Records of inspection surveys	***498***	***88***	***0***	***90***	***0***	***0***	***255***	***133***	***0***	***82***	***1.146***	***69,79***	***1.642***
Domestic ships	62	1	0	4	0	0	4	0	0	10	81	67,50	120
Foreign ships	20	0	0	0	0	0	0	0	0	0	20	153,85	13
Domestic boats	79	40	0	20	0	0	72	69	0	11	291	54,91	530
Foreign boats	78	43	0	38	0	0	129	63	0	59	410	64,77	633
Maritime domain	37	2	0	18	0	0	0	0	0	0	57	58,16	98
Safety of navigation facilities	74	0	0	1	0	0	0	0	0	0	75	79,79	94
Ports	71	2	0	0	0	0	0	1	0	2	76	100,00	76
Concession system	77	0	0	0	0	0	0	0	0	0	77	105,48	73
Other	0	0	0	9	0	0	50	0	0	0	59	1.996,67	3

Source: Authors

As it might have been expected, Table 5 shows that the largest overall number of inspections was carried out in Zadar. The busiest harbour branch offices were the Branch Offices in Sali and Božava on the island of Dugi Otok. These offices jointly perform inspections of boats and yachts, especially in the dense traffic area of the Telašćica Nature Park, a popular destination of many nautical tourists, both foreign and domestic.
Compared to Sali and Božava, the Branch Office in Biograd n/m performs fewer inspections although much more boats and yachts have been registered in Biograd than in Sali or Božava. Unlike the harbour branch office of Sali, the harbour branch office of Biograd does not have a specialised vessel for operations at sea, where most inspections are actually performed during the nautical season.
It is also obvious that most of the ships were inspected by the Harbour Master's Office in Zadar, i.e. by the safety of navigation inspectors, and that most of the inspected ships were registered in Croatia. On the other hand, most of the inspected boats were foreign vessels.
The harbour branch offices in Novigrad, Pag, Ist and Preko did not perform any inspection due to the retirement of the personnel in the beginning of 2015. This situation also affected the overall number of inspections of vessels in the area under the jurisdiction of the Zadar Harbour Master's Office, so that there were fewer inspections carried out in 2015 than in 2014. The only inspection category that increased in this period was the inspection of foreign ships.
In addition to the inspections of vessels, the central and branch offices of the Zadar Harbour Master's Office carried out the inspections of the maritime demesne, seaports and safety of navigation facilities such as lighthouses, coastal lights, buoys, radio-stations, electronic and radar systems, and other safety of navigation facilities.

5.1. Overview of search and rescue operations

This section presents an overview of all search and rescue (SAR) operations carried out by the Zadar Harbour Master's Office and its Branch Offices, in cooperation with the national Maritime Rescue Coordination Centre, seated in Rijeka, for the year 2015, compared to 2014 (http://www.mppi.hr/default.aspx?id=7397, 2016).

Table 6
Overview of SAR operations performed by the Harbour Master's Office in Zadar and its Branch Offices in 2015, compared to the operations performed in 2014

TYPE OF DATA	HARBOUR MASTER'S OFFICE AND HARBOUR BRANCH OFFICES										TOTAL	INDEX	TOTAL
	ZADAR	BIOGRAD n/m	NOVIGRAD	STARIGRAD	PAG	PREKO	SALI	BOŽAVA	IST	SILBA	2015		2014
SEARCH AND RESCUE operations													
Total number of SAR at sea	**23**	**0**	**0**	**8**	**0**	**0**	**1**	**0**	**0**	**0**	**32**	***60,38***	**53**
SAR operations involving Harbour Master's vessels	***23***	***0***	***0***	***0***	***0***	***0***	***1***	***0***	***0***	**0**	**24**	***60,00***	***40***
SAR operations involving Harbour Master's vessels and other participants	***0***	***0***	***0***	***8***	***0***	***0***	***1***	***0***	***0***	**0**	**9**	***-***	***0***
SAR operations involving ships and boats of other prticipants	***4***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	**0**	**4**	***33,33***	***12***
SAR operations supported by aircraft	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	**0**	**0**	***0,00***	***1***
Persons saved	**40**	**0**	**0**	**20**	**0**	**0**	**4**	**0**	**0**	**0**	**64**	***98,46***	**65**
Ships saved	**1**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**0**	**1**	***-***	**0**
Boats saved	**14**	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**0**	**0**	**22**	***110,0***	**20**
Total number of casualties	**4**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	***500,0***	**1**

Source: Authors

It is rather important to emphasise that the overall number of SAR operations was lower in 2015 than in 2014 (see Table 6). It is highly commendable that, despite the reduced number of staff (see Table 5), the safety of navigation was increased owing to frequent inspections performed by the Harbour Master's Office in Zadar and its Branch offices. The cooperation of the Harbour Master's structural units should be pointed out as well. The harbour branch offices of Starigrad and Sali, for instance, engaged in joint SAR operations. Apart from the central Harbour Master's Office in zadar, the Branch Office in Starigrad was the busiest unit due to specific meteorological conditions prevailing in the area throughout the year (the most frequent threat to the safety of navigation being north-easterly gale-force Bura).
In addition to human lives, considerable property was saved in search and rescue operations in 2015. The value of the saved property was 10% higher than in the previous year.

6. Conclusion

In Chapter IX, the Maritime Code, the fundamental legal document governing the inspectoral supervision of the sea traffic and the safety of navigation in the waters of the Republic of Croatia, specifies the responsibilities of the safety of navigation inspectors and authorised specialists in Croatia's Harbour Master's Offices and their Branch Offices regarding the implementation of inspection surveys of domestic and foreign ships, boats and yachts.
The comparative analysis of the statistical data referring to the years 2014-2015 resulted in the following conclusions: the number of registered ships and boats in 2014 and 2015 did not fluctuate much, i.e. their number remained almost the same. However, the number of registered yachts saw a sharp rise, mostly due to the newly registered yachts intended for personal use and recreational purposes. With respect to the overall traffic of seaborne passengers and vehicles, there was a decrease in their movement in 2015, compared to 2014, whereas the cargo traffic grew over the same period.
The increasingly frequent surveys of ships, boats and yachts performed by the safety of navigation inspectors and the authorised specialists acting in line with the ever stricter national regulations and instructions of the Ministry of

Maritime Affairs, Transport and Infrastructure, gradually resulted in an increased safety of navigation, safety of human lives at sea, and marine environment protection.
Even though the number of employees at the Zadar Harbour Master's central office and its branch offices was below the optimum, the inspection surveys of the domestic and foreign ships, boats and yachts were carried out frequently and thoroughly. Violations of maritime regulations were detected and sanctioned with great diligence, in compliance with the Maritime Code, with the purpose of enhancing the safety of navigation, safety of life at sea, and marine environment protection.
Regular inspections and performance of the safety of navigation inspectors and authorised specialists at sea increased the awareness across the nautical population, i.e. participants in maritime traffic, especially in summer when more than 20,000 vessels were present in the area under the jurisdiction of the Harbour Master's Office of Zadar. This has been confirmed by the statistical data which show that, in the year of 2015, there were much less search and rescue operations and property salvage operations than in 2014.

References

Harbour Master's Office Zadar – Department of inspection and Department of sea traffic and SAR - official web-site. Available from Internet: <http://www.mppi.hr/default.aspx?id=7397>. [accessed 2016-05-12].
Maritime Code. 2004. *Narodne novine,* 2004(181).
Maritime Code. 2007. *Narodne novine,* 2007(76).
Maritime Code. 2008. *Narodne novine,* 2008(146).
Maritime Code. 2011. *Narodne novine,* 2011(61).
Maritime Code. 2013. *Narodne novine*, 2013(56).
Maritime Demesne and Seaports Act. 2003. *Narodne novine*, 2003(158).
Maritime Demesne and Seaports Act. 2006. *Narodne novine*, 2006(141).
Maritime Demesne and Seaports Act. 2009. *Narodne novine*, 2009(38).
Ministry of Maritime Affairs, Transport and Infrastructure - official web-site. Available from Internet: <http://www.mmpi.hr>. [accessed 2016-05-12].
Stanivuk, T.; Medić, B.; Medić, M. 2015. Statistical Review of Inspections of Navigation Safety in the Croatian Ministry of Maritime Affairs, Transport and Infrastructure during the Past Five Years, *Suvremeni promet: časopis za pitanja teorije i prakse prometa*, 35(3-4): 186-189.
Stanivuk, T.; Medić, B.; Medić, M. 2015. Statistical Review of the Annual Report on the Performance of Maritime Safety Inspection in Croatia, *Transactions on Maritime Science* 4(1): 41-51. Available from Internet: http://www.toms.com.hr/archive/vol4/no1/toms_vol4no1_doi005.pdf.
Tomašević, M.; Ristov, P.; Stanivuk, T. 2007. *Metodologija znanstvenog istraživačkog rada - statističke metode u istraživanju*, Faculty of Maritime Studies, University of Split, Split.

ASPECTS OF DEVELOPMENT OF CONTINENTAL COMBINED TRANSPORT IN THE CZECH REPUBLIC

Jaromír Široký[1], Pavlína Hlavsová[2], Hana Vohanková[3]
[1,2,3] University of Pardubice, Jan Perner Transport Faculty, Department of Transport Technology and Control, Studetnstká 95, CZ-53210 Pardubice, Czech Republic

Abstract: This paper describes the current state of combined transport, and especially continental transport, in the Czech Republic, and aspects of its potential further development. The role of continental CT is particularly important in logistics chains, mainly in transporting palletised goods.

Keywords: combined transport, continental transport, logistics chains, development.

1. Current state of CT in the Czech Republic

Currently, only unaccompanied combined transport ("CD") is operated in the Czech Republic, mainly using ISO 1A containers due to the subsequent maritime transport. Moreover, swapbodies and intermodal road semitrailers are operated in the Czech Republic as well. However, their share in the total volume of CT is low. Statistical transport yearbooks show that the share of swapbodies and intermodal road semitrailers in CT in the Czech Republic in 2015 was 7.3% by gross tonnage transported (see Table 1 and Fig. 1).
It is the continental transport performed by other systems (not containers) that has a great potential. Since 2005, national transport of woodchips has been performed in special inland containers by integrated trains, and in 2012, sludge started to be transported in this way from North Moravia to Bohemia. In October 2005, international continental CT routes Lovosice–Duisburg were introduced, and in June 2006, Lovosice–Hamburg–Billwerder; these are mainly suitable for the transport of swapbodies and intermodal road semitrailers. Since 2010, CT transport operations with a regular transport of containers, swapbodies and intermodal road semitrailers have started to be performed on the routes Ostrava–Lovosice–Duisburg, Ostrava–Verona, Brno–Rostock as well. In 2012, transport started to be performed on another route Praha–Uhříněves–Duisburg, where ISO 1 containers are transported.

Table 1
Total volume of CT in the Czech Republic between 1995–2014 [thousand GT]

Year	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Unaccompanied total	1.224	2.971	3.127	3.651	4.250	4.690	5.338	5.937
Accompanied by rail Ro-La	2.557	3.122	2.463	2.149	2.784	837	0	0
CT TOTAL	3.781	6.093	5.590	5.800	7.034	5.527	5.338	5.937
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Unaccompanied total	7.155	7.614	6.818	8.352	9.380	10.212	11.155	12.387
Accompanied by rail Ro-La	0	0	0	0	0	0	0	0
CT TOTAL	7.155	7.614	6.818	8.352	9.380	10.212	11.155	12.387

Source: Transport yearbooks 1995–2014, MD, adapted by authors

The ISO 1 containers are frequently used in continental CT transport, where it is necessary to change the gauge on the route. The ISO 1 containers are deployed on regular routes between ŠKODA AUTO Mladá Boleslav and Kaluga and Nizhny Novgorod (Russian Federation) – integrated trains. Moreover, ISO 1 containers are transported from the Paskov container freight station to Kazakhstan – groups of wagons. The results of these container continental transports cannot be established as carriers and CT operators consider these results for individual years as their trade secrets (ŠKODA AUTO Mladá Boleslav, Express-Interfracht, etc.). These national transport operations, not only those performed by ISO 1 containers, account for as much as 10% of CT, as estimated by the research team.
For the use of swapbodies and intermodal road semitrailers in CT to be significantly greater, there is no efficient incentive for road carriers and shippers. Even though road carriers own swapbodies (albeit often without rail transport authorisation[2]) and operate them in the Czech Republic, they only use them in the regular road freight transport. Moreover, road carriers mostly own shorter series C swapbodies, which is not ideal for CT due to higher reloading costs (one reloading of a series A swapbody corresponds to reloading of two series C swapbodies). The number of swapbodies used in the territory of the Czech Republic cannot be established; these are not freight vehicles and there is no national register and statistics. In CT, these transport units are mainly used by foreign road carriers and shippers (for

[1] Corresponding author: jaromir.siroky@upce.cz
[2] UIC railways and UIRR operators approved a plan of attributing ILU-Codes to transport units (swapbodies, intermodal road semitrailers). The plan started to be performed in July 2011, when UIRR started giving out ILU-Codes for marking these units with code stamps. Since July 2014, only ILU codes (swapbodies, intermodal road semitrailers) and BIC (ISO 1 containers) have been accepted. It is expected that after a 8-year transition period since the introduction of ILU-Codes (July 2019), all transport units are to be equipped with the new code stamps. Presently (March 2016), 7 Czech entities are registered in the ILU register.

instance DB Schenker, LKV Walter, DSV, DHL), even though swapbodies are very advantageous for CT (mainly for palletised goods). Due to their dimensions and construction, they cannot be transported on sea-going vessels – i.e. in maritime (intercontinental) transport.

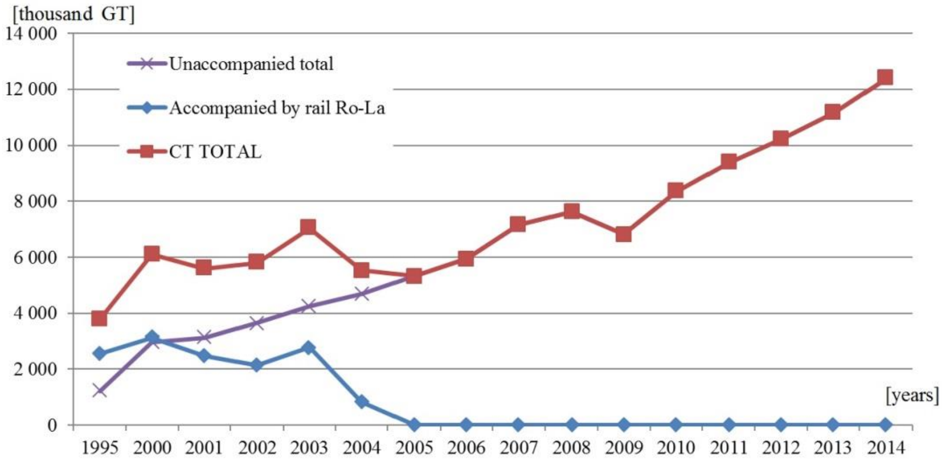


Fig. 1.
Total volume of CT in the Czech Republic between 1995–2014 [thousand GT]
Source: Transport yearbooks 1995–2014, MD, adapted by authors

The development of unaccompanied CT can be assessed as very positive. Its gradual increase is closely connected with the increase of world trade and the ever increasing maritime transport of ISO 1 containers mainly from/to Asia. As a result, the transport of containers by rail from/to large European ports (mainly Hamburg, Bremerhaven, Rotterdam, Koper, to a lesser extent also Rostock, Pireus and Trieste) increases as well, these cities being the key source and target points for international CT (see Fig. 2). That is why the number of direct integrated trains on the routes from/to ports is increasing and other subsequent routes are introduced from hub container freight stations in the Czech Republic by significant CT operators.

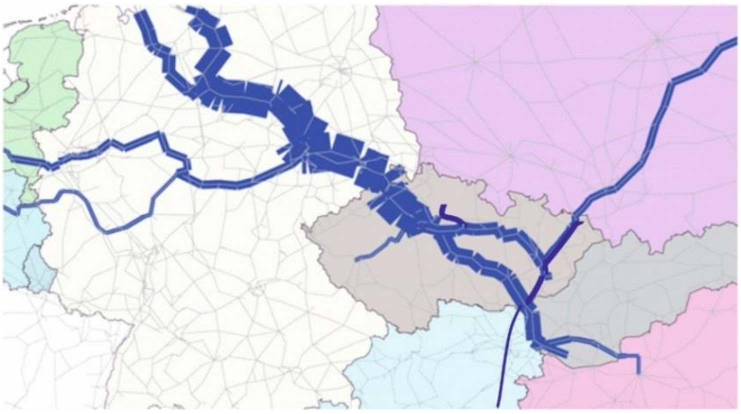


Fig. 2.
Main streams of goods in CT in the Czech Republic
Source: DIOMIS project, adapted by authors

Table 2
Transport of full and empty transport units in CT by rail between 2000–2014 [thousand GT]

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Containers	2.651	2.773	3.410	4.052	4.556	5.355	6.061	7.442	8.001	7.129	8.597	9.406	9.999	11.252	12.127
Swapbodies	450	491	480	420	363	277	187	170	167	137	230	296	353	156	159
Intermodal semitrailers	0	0	0	0	0	2	24	24	25	49	102	304	493	715	802
TOTAL	**3.101**	**3.264**	**3.891**	**4.493**	**4.919**	**5.634**	**6.272**	**7.636**	**8.193**	**7.315**	**8.929**	**10.006**	**10.845**	**12.123**	**13.088**

Source: Transport yearbooks 2000–2014, MD, adapted by authors

The use of individual CT systems is described in Table 2 and Table 3, showing the number of full and empty transport units in CT by rail in thousand GT and thousand TEU. It shows that the support of transport unit purchase between 2005–2010 resulted in an increase of transport mainly of intermodal road semitrailers by rail of several dozens of percent. Therefore, there is room for the use of transport units used in continental CT, especially intermodal road semitrailers or swapbodies. That is why the aim of this project is to provide methodology to further support the development of these CT systems.

2. Aspects of further development of continental combined transport

To achieve a greater use of CT, it is necessary to at least partially compensate the price differences compared to road transport. Before the costs for using a transport route are harmonised, a transport policy should be implemented that would at least in part eliminate these disproportions, ensuring more comparable conditions for CT. This is also in full accord not only with the White Paper on European transport policy (support of competitiveness of rail transport), but also with the results of the RECORDIT project (Real Cost Reduction of Door-to-Door Intermodal Transport) as part of the EU Fifth Framework Programme.

Yet another reason is the fact that the projects are not profitable in the initial phase as CT can only be efficient in directions where the streams of traffic are concentrated, and therefore it takes some time for a new system or CT route to gain market share. Only an integrated train with a capacity of 40 to 60 transport units usually starts to be profitable, its average utilization being at least 80% in both route directions.

It is not possible to make customers use a certain type of transport. For customers ordering shipping, several criteria may be of importance (speed of transport, shipment arriving in time, safety and reliability of transport, related services and their frequency); however, what is important is usually the price. Customers usually don't care that the safety of rail traffic is many times higher and most emissions are on a much lower level. This is related to the fact that these external costs are not internalised. In accordance with the White Paper, the average ratio of externalities in road and rail freight transport is about 4.5: 1. The internalisation of externalities is one of the most problematic issues in transport, and due to its complexity it has not been satisfactorily resolved either in the Czech Republic, or in any other EU state.

Not only the government, but also municipalities, regions, non-governmental organisations and other entities aim to support such types of transport that have the lowest negative impact on the environment. That is why the development of CT is supported, as emphasised by the EU White Paper as well. Therefore it is necessary to ensure a better integration of individual types of transport and at the same time, to provide for a significant potential transport capacity serving as connections in an efficiently managed logistics chain connecting all individual transport services.

The support of transport unit purchase depends on several other factors, dealt with by the authors separately below.

2.1. Reloading equipment for transport units in continental CT

Another significant factor is the high cost of investment necessary for implementing new CT system technologies and for construction or modernisation of infrastructure necessary for its further development. The modernisation of existing and construction of new CT container freight stations (meeting the requirements of the AGTC Agreement, Regulation of the European Parliament and Council 913/2010, 1315/2013, and 1316/2013), either independent or as part of public logistics centres, renewal or completion of rail fleet for CT, purchase of transport units and reloading equipment, and ship modification entirely depend on business plans; however, these are influenced by framework conditions.

It is to be noted that the development of continental CT systems is also related to technical and technological equipment of public CT container freight stations in the Czech Republic. Most publicly accessible container freight stations in the Czech Republic are equipped with reloading equipment including both spreaders for the reloading of ISO 1 containers, and spreaders with collets for vertical reloading of swapbodies and intermodal road semitrailers (see Table 3). Adding collets to reloading equipment is not very costly, as their price is around CZK 800,000[3] (purchase price of the Kalmar reloading equipment being around CZK 9 million). Considering the newly arranged supplier-customer relationships and the increasing number of transport operations, the price of collets as an addition to the reloading equipment is rather negligible.

Table 3

Overview of publicly accessible container freight stations with reloading equipment with collets in the Czech Republic (as of 06/ 2016)

Operator/owner	Container freight station	Number of reloading mechanisms with collets
ČD-DUSS, Terminál, a.s.	Lovosice	2
Rail Cargo Operator – CSKD s.r.o.	Mělník port Přerov	3 1
Terminal Brno	Brno-Horní Heršpice	2
METRANS, a.s., Praha	Česká Třebová Nýřany (near Plzeň) Praha-Uhříněves	1 1 2

[3] It is very demanding to operate the additional collets – the reloading equipment is not fully synchronised to manipulate with the device, i.e. the reloading must be performed by more workers and it takes a longer time. Additional collets reduce the carrying capacity of the reloading equipment by 1–1.5 t. It also usually takes several weeks to equip the reloading equipment with these additional collets. The purchase of a new reloading equipment is much more costly and the purchase time is very long (several months), as it not only depends on the manufacturing of the equipment, but also on the delivery, mounting and putting into operation.

Operator/owner	Container freight station	Number of reloading mechanisms with collets
	Šenov (near Ostrava) Želechovice (near Zlín) Ústí nad Labem	1 1 1
Star Container s.r.o., Mělník	Mělník port	1
AWT, a.s., Ostrava	Paskov (near Ostrava)	3

Source: Rail Authority, adapted by authors

The equipment of container freight stations for reloading of not only containers, but also swapbodies and intermodal road semitrailers is very important. The use of the particular transport unit is related to the number of manipulations during reloading at container freight stations (see Table 4). To compare the prices of reloading, articulated vehicles and road trains are considered. For containers, the use of articulated vehicles is considered (one ISO 1 A container or two ISO 1 C containers) or road trains for two ISO 1 C containers. For swapbodies, articulated vehicles are considered (one A swapbody – very rarely transported in the Czech Republic) or road trains for two C swapbodies. During reloading at the container freight station, the road set brings the transport units to a lay-by, and then the reloading from the lay-by to railway wagons takes place (or reversely). At the container freight station, the transport unit is thus reloaded twice. For C swapbodies and 1C ISO containers, it is necessary to account for a double number of manipulations (for road sets). Therefore even the number of manipulations in these types of transport unit is an important factor as the price of reloading increases. For intermodal road semitrailers, only one manipulation is considered[4] during reloading at the CT container freight station, whereas for ISO 1 A containers[5] or A swapbodies, there are two manipulations[6]. In collection or distribution of transport units to/from the container freight station, the types of manipulations with the individual units are not recorded for statistical purposes. Therefore in determining the price of manipulation, the above mentioned numbers of manipulations are taken into account.

Table 4
Number of manipulations at CT container freight stations for selected transport units

Transport unit	Number of manipulations at container freight station	Costs of one manipulation [EUR]	Costs of reloading of transport unit for articulated vehicle / road train [EUR]
ISO 1 A container	2	23	46
ISO 1 C container	4	23	92
A swapbody	2	25	50
C swapbody	4	25	100
Intermodal road semitrailer	1	32	32

Source: authors

2.2. Length and capacity of CT train

It is also necessary to point out the influence of CT train length and capacity. Presently, CT trains being around 550–630 m long (including the length of the power unit – 20 m) have a capacity of around 71–92 TEU. However, this value depends on the number of individual railway wagon series and their combinations. Individual CT operators in the Czech Republic use different series of railway wagons (for the transport of containers, swapbodies, intermodal road semitrailers). The following Table 5 illustrates the main series of railway wagons used in CT in the Czech Republic and shows the capacities of train sets in TEU for train length of 550–750 m (taking into account the recommended length of train of 740 m in accordance with Regulation 1315/2013).

Table 5
Capacity of CT train of a length of 550–750 m in different railway wagon series [TEU]

Railway wagon			Length of train [m]					
series	length [m]	capacity [TEU]	550	600	650	700	740	750
Sggrss	26.4	4	80	88	96	104	112	112
Sgnss	19.7	3	81	90	96	105	111	114
Sggmrss	29.6	4	72	80	84	92	100	100
Sggnss 80´	25.9	4	84	92	100	108	112	112

[4] During reloading of intermodal road semitrailers at the container freight station, the semitrailer is put on the lay-by upon arrival of the articulated vehicle at the container freight station. The actual reloading of the intermodal road semitrailer on a railway wagon (and reversely) is performed using reloading equipment, being considered by the container freight station operator as one manipulation.

[5] As it is possible to store ISO 1 A containers (or ISO 1 C containers), they are sometimes manipulated with at the container freight station. These technological manipulations are not counted as manipulations.

[6] During reloading of ISO 1 A containers or A swapbodies at the container freight station, the transport unit is put on the lay-by by the reloading mechanism upon arrival of the articulated vehicle at the container freight station. The actual reloading of the transport unit to a railway wagon is performed by the reloading mechanism and is counted as another manipulation (i.e. there are two manipulations).

Sdggmrs	34.2	4.8*	76	81	91	96	100	100
Sdggmrss TWIN	34.2	4.8*	76	81	91	96	100	100

Note: the capacity of 4.8 TEU corresponds to transportation of 2 intermodal road semitrailers on 1 railway wagon.
Source: authors

The length of train stated above includes the length of the power unit of 20 m. The individual combinations are not mentioned here as they are different for different CT operators. It is obvious from the overview that using a train with a length of up to 750 m (in accordance with AGTC Agreement recommendations), or 740 m (in accordance with Regulation 1315/2013), the capacity of the train set increases by approximately 30 TEU, which is very positive in economic terms. However, it is necessary to take into account that using a 750 m long train is very advantageous from the economic perspective, but very problematic from the operational point of view as in the Czech railway network, there are very few intermediate railway stations, at which overtaking or crossing of trains of such length would be possible on running tracks. That is why trains of such length cannot be counted on as of yet. The researchers suggest to use trains with a length of 650–700 m.

2.3. Support of CT abroad

In the EU, the support of combined transport is established by the Combined Transport Directive (Council Directive 92/106/EEC). The Directive aims to support certain types of combined transport eliminating authorisation procedures and quantitative restrictions for certain types of combined transport, clarifies the non-application of restrictions on road cabotage in road transport, and provides financial support for certain types of CT by means of tax incentives. In accordance with the provisions of the Combined Transport Directive, the combined transport of goods is to meet several specific criteria, mainly as to the type of transport units and distances.
The Combined Transport Directive is complemented by several other EU provisions, such as the directive regulating the weights and dimensions (Directive (EU) 2015/719 amending Council Directive 96/53/EC) laying down for member states to allow the movement of heavy duty intermodal transport units on the road, where they are used in CT. Moreover, the EU provides financial support to projects related to combined transport.
In line with the general EU transport policy, the aim of the provisions is to reduce the share of road freight transport and to support more environmentally friendly modes of transport with better energy efficiency. CT is supported in four main areas:

1. Internalisation of external costs in all modes of transport to provide adequate price signals to users, operators and investors. Social and environmental costs of transport should be paid taking into account its polluters.
2. Greater share of targeted investments in infrastructure to allow for better links between individual modes of transport.
3. Better use of information (on transport, capacity, availability of infrastructure, cargo and vehicle position).
4. Direct support of intermodal transport, as laid down in the Combined Transport Directive (Council Directive 92/106/EEC) aiming at increasing the competitiveness of combined transport.

What plays a crucial role in the development of CT in individual EU member states are the legislative regulations of this support, i.e. either laws or regulations. Before these provisions are issued, they are usually discussed with EU institutions. Even though the form and content of the individual ways of support are different, there is one common aim: to harmonise costs between direct road transport and CT.
In 2011, the European Commission presented a new plan of the European core multimodal network (it is to present instructions, schedules /road maps/ and financing plan of the TEN-T Trans-European network). EU financial means from TEN-T funds, cohesion fund and structural funds are to be used conceptually, and therefore they will be provided within a single framework.
In January 2015, the final report of project FV355/2012/MOVE/D1/ETU/SI2.659386 (Analysis of the EU Combined Transport[7]) was presented in Frankfurt am Main. Besides the actual analysis of CT systems in individual EU member states, the report also covered the support of CT in individual states. The support of CT was treated from two perspectives. The first one was the history of support in different countries or different projects and its impacts on the development of CT. The second one were recommendations for further support of CT development in the EU. The support should be provided in the following areas:

- subventions for the construction and modernisation of CT terminal infrastructure;
- subventions for the purchase and modernisation of CT reloading equipment;
- subventions for the construction of CT terminal allowing for non-discriminatory access of the operator to individual terminal users;
- creation of the Single European Transport Area as the core network of strategic infrastructure;
- moreover road vehicle parameters in different member states should be harmonised so that it is possible to use the option of a greater weight of shipments in international transport than in national transport (increase from 40 t to

[7] Project FV355/2012/MOVE/D1/ETU/SI2.659386 called Analysis of the EU Combined Transport was carried out by KombiConsult GmbH (Frankfurt am Main), Intermodality Ltd (Lewes), PLANCO Consulting GmbH (Essen) and Gruppo CLAS S.p.A. (Milan). The complete final report is available at: http://ec.europa.eu/transport/themes/strategies/studies/doc/2015-01-freight-logistics-lot2-combined-transport.pdf

44 t). Borderland areas will have better access to terminals abroad;
- long stays caused by transition to a different railway network will be eliminated using interoperable power units;
- harmonization of costs of access to transport infrastructure in the whole of Europe.

2.4. Logistics use of transport units in CT

In terms of transport of palletised goods (goods on Euro-pallets of 800 mm x 1200 mm) in continental CT, it is the A and C swapbodies or intermodal road semitrailers that are most advantageous for these, due to the inner space of the transport units (see Table 6). In both these transport units, it is possible to load up to 33 Euro-pallets (in one layer). It is by 37.5% more compared to the ISO 1 A container, even though in transporting these units by rail, an equivalent number of railway wagons is necessary. That is why for customers requiring the transport of palletised goods, these transport units suitable for continental CT are more advantageous than the use of regular maritime containers. Comparing these transport units, we can see that goods transported in three ISO 1 A containers[8] can be transported in only two A swapbodies or two intermodal road semitrailers. This results in a significant reduction of the number of transport units transported, and also the number of railway wagons used.

Table 8
Comparison of selected technical specifications in transport units

Transport unit	ISO 1 A container	Inland 45' PW container	C swapbody	A swapbody	Intermodal road semitrailer
length [mm] width [mm] height [mm]	12.192 2.438 2.896	13.716 2.500 2.896	7.820 2.550 2.700	13.600 2.500 3.000	13.600 2.500 3.005
number of Euro-pallets [pieces]	24	33	17	33	33
internal volume [m^3]	68	84	42	90	100
Empty weight [kg]	4.200	5.870	2.400	4.900	6.500–7.500
Maximum net weight [kg]	28.100	28.130	13.600	29.100	26.500–27.500
Maximum gross weight [kg]	30.500	34.000	16.000	34.000	34.000
Purchase price [CZK]	42.000	220.000	350.000	450.000	800.000

Source: CARU, Kögel, authors

At depots and logistics centres, terminal tractors are often used for the manipulation of swapbodies from lay-bys to loading platforms. These terminal tractors have to be purchased (the price of these tractors is around CZK 2 million). However, these tractors are not used in all depots or logistics centres. That is why the whole road train (lorry + trailer) is driven to the loading platform. However, this offsets the significant advantage of swapbodies (saving the driver's waiting time during unloading or loading).
On the other hand, when using the intermodal road semitrailers, the tractor drives the semitrailer to the loading platform and leaves it there. As in swapbodies, it then drives to the lay-by (or to another platform) and loads another intermodal road semitrailer. That is why there is no waste of time for the driver (tractor) during the loading or unloading. This is one of the significant advantages compared to ISO 1 containers that are mounted on the road semitrailers and can't be manipulated with during loading or unloading.
What also plays a crucial role is the purchase price of individual transport units suitable for continental CT. Table 6 describes basic technical specifications together with price for these transport units. For comparison, ISO 1A container parameters are mentioned here as well. In terms of price and inner volume, it is best to use A swapbodies. However, the companies using swapbodies asked mostly use C swapbodies (C745 or C782).

3. Conclusion

This paper describes the current state of combined transport, and especially continental transport, in the Czech Republic and aspects of its potential further development. The role of continental CT is particularly important in logistics chains, mainly in transporting palletised goods. This is also the main output of this paper. Within the Operational Programme of the Ministry of Transport, support will be granted for the construction of CT infrastructure (mainly CT terminals) and also for the purchase of new transport units for continental CT. There are many other factors that can influence the use of CT in the Czech Republic; however, these are beyond the scope of this paper.

[8] ISO 1 A containers are mainly used in continental CD in transport operations requiring a change of gauge (from 1435 mm to 1520 and vice versa) or in combination with ferry transport.

Acknowledgements

This paper has been supported as part of the TAČR TB0500MD004 “Proposed system of support of continental combined transport – transport units” project and SG540001/20/51030 ”Student grant competition“ project.

References

Global Logistics for Central Europe. Metrans. Available from Internet: <http://www.metrans.eu/>.

Multimodal transport systems. CVUT Transport Faculty. Available from Internet: <http://www.fd.cvut.cz/projects/k612x1mp/vn.html>.

Novák, J.; Cempírek, V.; Novák, I.; Široký, J. *Combined transport*, University of Pardubice, Inc. Czech Republic, 342 p.

Project FV355/2012/MOVE/D1/ETU/SI2.659386 Analysis of the EU Combined Transport. Available from Internet: <http://ec.europa.eu/transport/themes/strategies/studies/doc/2015-01-freight-logistics-lot2-combined-transport.pdf>.

Project N 226/2006 Combined Transport, Wien. Available from Internet: <http://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_N226_2006>.

Public consultation on Combined Transport: Report on the contributions received. Available from Internet: <http://ec.europa.eu/transport/media/consultations/doc/2014-combined-transport/summary.pdf>.

SA 38152 Support scheme for rail transport (2014/N) — Italy — Emilia Romagna region — aid in favour of rail freight transport, Brussel. Available from Internet: <http://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_SA_38152>.

SA.32603 Subsidy scheme "Ferrobonus" for combined transport and SA.38152 Support scheme for rail transport. Wien. Available from Internet: <http://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_SA_32603>.

SA.33486 Förderprogramm Umschlaganlagen für den kombinierten Verkehr, Brussel. Available from Internet: <http://ec.europa.eu/competition/state_aid/cases/242238/242238_1469822_54_2.pdf>.

SA.33993 Aid for the provision of certain combined transport services by rail in Austria. Wien. Available from Internet: <http://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_SA_33993>.

SA.41100 Special Guidelines for the Programme of Aid for Innovative Combined Transport for 2015-2020. Brussel. Available from Internet: <http://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_SA_41100>.

Sonderrichtlinien - IKV Innovationsförderprogramm Kombinierter Güterverkehr (1.1.2015 bis 31.12.2020), Herausgegeben vom Bundesministerium für Verkerh, Innovation und Technologie, Wien. Available from Internet: <https://www.awsg.at/Content.Node/files/kurzinfo/Kombinierter-Gueterverkehr-Merkblatt.pdf>.

Transport policy of the Czech Republic for the period 2014 - 2020. Available from Internet: <http://www.mdcr.cz/NR/rdonlyres/099AB8C6-3DD2-4621-9E83-FA26B84B4A24/0/DP1420verze15_01_2013.pdf>.

White Paper – Concept of public transport 2015-2020 with a view to 2030. Available from Internet: <http://www.mdcr.cz/NR/rdonlyres/09044F16-6D71-470D-88D8-727F6B52C117/0/MD_Bila_kniha.pdf>.

LOCATING CITY LOGISTICS TERMINAL BY APPLYING THE COMBINED QFD-VIKOR METHOD

Snežana Tadić[1], Slobodan Zežević[2], Mladen Krstić[3]
[1,2,3] *University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia*

Abstract: Locating the city logistics terminal (CLT) is a strategic problem and various city logistics stakeholders are interested for its solution. All of them are generating the requirements that can be achieved through the definition of multiple criteria, based on which the location that most closely meets the expressed requirements is chosen. For the solution of the defined problems this paper proposes a model that combines the Quality Function Deployment (QFD) and Višekriterijumska Optimizacija i kompromisno Rešenje (VIKOR) methods. QFD method is used to establish the connections between requirements and criteria, as well as to obtain the criteria weights, while VIKOR method used for the evaluation of potential locations and selection of the best one in terms of considered criteria. The applicability of the proposed model is demonstrated by solving the real-life case study of locating the CLT in the territory of Belgrade.

Keywords: city logistics terminal, location, QFD, VIKOR.

1. Introduction

The city is the place of the largest concentration of economic and social activities, and logistics is very important for the sustainability and the economy of the city. With growing demands for a more efficient supply and environmental protection grows the interest in city logistics, i.e. goods distribution, and logistics systems of urban areas. Problems of supplying the city with goods and extracting materials from the urban areas are present and solved in accordance with varying degrees of economic, cultural, technological and other aspects of social development. The main problem is the lack of planning activities, comprehensive and long-term policy of city logistics. Urban planners' decisions are often inadequate, without the necessary research, analysis and insight into different measures and impacts.
The above mentioned problems and the complexity of logistics in urban areas, but also social, cultural, demographic characteristics of the city, architectural heritage, habits and attitudes of the population, caused the development of different conceptions of city logistics (Tadić et.al, 2014, 2014B). In a variety of different conceptual solutions logistics centers stand out. The concept is based on the channelling of goods and transport flows from different providers towards the logistics center and consolidated deliveries to the generators in the urban areas. In this way, logistics centers are becoming the central element of the system for the supply of goods and extraction of waste material. Depending on the size and characteristics of the cities, the number, size and location of logistics centers vary. Logistics centers play an important role not only in the supply chain, but also in planning of the city logistics as a whole, and their location has a significant impact on the performance of city logistics, i.e. on the large number of parameters of the urban environment and logistics flows (Tadić, 2014, Tadić & Zecevic, 2016). They are being established on the traffic-favourable locations on the outskirts of the cities, or in the immediate urban areas, and connecting the inbound/outbound flows, i.e. coordinating the flows of goods in the process of supply and extraction from the urban areas. Location of the city logistics terminal, in relation to the target market, significantly affects traffic and the environment, as well as the economic parameters of the adopted concept of consolidation (Tadić *et.al*, 2012).
Taking into account the specificity of the problem, different authors have dealt with the CLT location selection by applying specialized location models (e.g. Guyon *et.al*, 2012), multi-criteria analysis (e.g. Awasthi *et.al*, 2011, Tadić *et.al*, 2012), or their combination (e.g. Rhine *et.al*, 2011). In this paper the problem of locating CLT is solved using the combined VIKOR-QFD model. In general, the Quality function deployment (QFD) is a method for planning and development of the product/service which allows clear identification of needs and requirements of the users and development of a product/service which will meet the customer expectations to the greatest extent. It involves the formation of the House of Quality (HOQ) that illustrates the connection between user requirements (WHAT?) and qualitative characteristics (HOW?). Višekriterijumska Optimizacija i kompromisno Rešenje (VIKOR) method provides a compromise solution, i.e. achieves a maximum group utility and a minimum individual regret of the opponents, and in addition to considering the distance from the ideal solution, takes into account the degree of satisfaction of each criterion. The applicability of QFD and VIKOR methods are already proved, but there are not many papers in which these methods are used for solving the location problems. In this paper, the QFD method is used to establish the connection between the location requirements (WHAT?) and location criteria (HOW?) that will ensure the fulfilment of the requirements. The results are the criteria weights used in the second part of the model, in which the VIKOR method is applied for selecting the most appropriate alternative, i.e. potential location of the CLT.
The paper is organized as follows. Chapter 2 gives a detailed description of the proposed model and the steps for its implementation. Solving the case study of a CLT location selection on the territory of Belgrade is described in Chapter 3. Finally, conclusions and directions for future research are given at the end of the paper.

[3] Corresponding author: m.krstic@sf.bg.ac.rs

2. QFD-VIKOR model

This paper proposes a new hybrid model which is based on a combination of QFD and VIKOR methods for the solution of the defined problem, i.e. city logistics terminal location selection. QFD method is used to establish the connection between the location requirements and the location criteria based on which the defined requirements will be met. As a result of the QFD method, values of the criteria weights are obtained, by which the alternatives, in this paper city logistics terminal potential locations, are evaluated. VIKOR method is used for obtaining the final order of the alternatives. QFD and VIKOR methods are described below in more detail.

QFD method is created in Japan in the period between 1967 and 1972 as a result of a number of different initiatives (O'Connor, 1990), although Dr S. Mizuno (1994) is considered as the creator of this method because he gave the largest contribution to its development. QFD represents a well-structured, multi-functional method for adequate planning, developing, designing and manufacturing of any product or service based on user requirements. In general, the method involves creation of the House of Quality whose elements are user requirements on one side and technical (design, development) requirements (features)on the other. The goal is to perform prioritization of the user's requirements and obtain the weights of technical requirements, while maximizing user's satisfaction, based on the established connections between the user's and technical requirements.

QFD has a long history and a wide range of application in various fields (Chan & Wu, 2002). It is a powerful tool for quality planning, continuous improvement, decision making etc. In addition, the matrix of HOQ is an almost universal tool that can be used to prioritize most of the tasks in any field. QFD method has many advantages. It is user oriented, i.e. in the process of structuring the problem it takes into account users' requirements and feedbacks regarding the observed problem. QFD enables faster development of products or services because it focuses on the specific requirements of users who are clearly identified. It is focused on the teamwork, i.e. all decisions are based on consensus, which is achieved through discussion and exchange of views between participants in the process. Another advantage of the QFD method is documentation of all the data related to the realization of the process, which allows continuous verification of compliance with the users' demands and timely response in case of changes. The method also allows prioritization of user requirements while finding innovative solutions for these requirements, thus improving the process and achieving maximization of the effectiveness. In this way the user expectations can even be exceeded (Sularto *et al.*, 2015).

For obtaining product or service of the appropriate quality a variety of so-called quality control methods can be used, one of which is the QFD method. However, unlike some other methods such as Control charts, Process Capability, etc. which control the "manufacturing" process of the products or services, or methods such as Sampling plans, Dodge-Roming tables, OC curves, etc. which inspect the quality of the finished products or services, QFD method provides adequate quality in the process of development or design of the products or services (Scholz, 2013, Shahin, 2008). In addition, compared to some other methods, e.g. Taguchi method, Shainin method, Conformability analysis, Poka Yoke, etc., which also ensure the quality of the product/service development process, QFD method is more flexible, it can be easily modified, extended and combined with other methods and is more suitable for achieving the appropriate level of quality in terms of users, i.e. it is "closer" to users than other methods (Shahin , 2008). For the above reasons, the QFD method is chosen in this paper.

The VIKOR method was first proposed by Opricovic (1998) for multi-criteria optimization of complex systems with the Serbian name: VIseKriterijumska Optimizacija i kompromisno Resenje (meaning multi-criteria optimization and compromise solution). The VIKOR method is convenient for the selection problems because of its stability and ease of use with cardinal information. Another advantage is that it considers the lowest performance rating with respect to a specified criterion (Tsai *et al.*, 2011). The method focuses on ranking and selecting from a set of alternatives against various, and in most cases conflicting and non-commensurable, decision criteria and determines compromise solutions for a problem. Here, the compromise solution is a feasible solution which is the closest to the ideal, and a compromise means an agreement established by mutual concessions. The obtained compromise solution can be accepted by the DMs because it provides a maximum group utility of the majority and a minimum of the individual regret of the opponent. The compromise solution can be the basis for negotiations containing the DM's preference by criteria weights (Opricovic & Tzeng, 2004).

Different MCDM methods can be used to rank the alternatives, but after comparing them the VIKOR method is chosen for solving the defined problem. The ELECTRE method has the capability to manage non-homogeneous variables and different types of criteria, but it often does not lead to the definition of only one solution emerging among the others but a subset of preferable solutions. Therefore, this method is considered more suitable for decision problems characterized by not many criteria and alternatives (Caterino *et al.*, 2008). The PROMETHEE I method has a clear approach to the decision problem and a degree of complexity depending on how the decision maker wants to model the preference function according to each criterion. However, the method very often does not lead to a complete ranking of alternatives, actually not solving the given problem. The version II of the same method, instead, always allows a complete ranking of options, but it requires a manipulation of the available information that does not always have a logical meaning (Caterino *et al.*, 2008). The TOPSIS and VIKOR methods approach the decision problem in a similar manner. They both define an ideal solution combining the best performances of the alternatives according to each criterion and perform ranking of the alternatives with respect to their distances from the ideal solution. However, the TOPSIS does not consider the relative importance of these distances (Hwang and Yoon, 1981). The highest ranked alternative by VIKOR is the closest to the ideal solution, while the highest ranked alternative by TOPSIS is the best in

terms of the ranking index, which does not mean that it is always the closest to the ideal solution. Moreover, the VIKOR method proposes a compromise solution with an advantage rate (Caterino et al., 2008, Opricovic & Tzeng, 2004).
The steps of the proposed model are described below, and the scheme of the proposed model is shown in Figure 1.

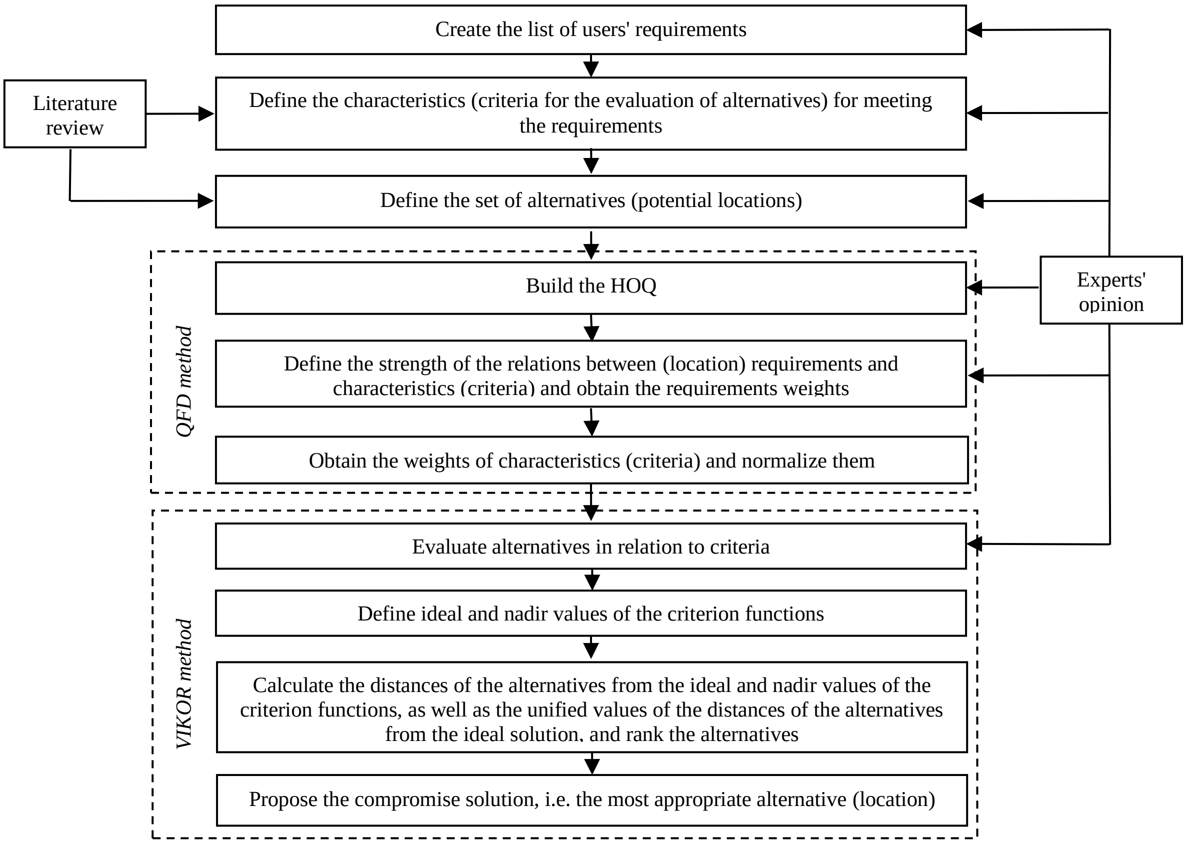


Fig. 1.
Proposed QFD-VIKOR model

Step 1: Define the problem structure. It is necessary to determine the structure of the requirements, in this paper requirements that city logistics terminal location must meet, a set of alternatives - potential locations of the terminal, as well as the criteria for selection of the alternative - location, which will ensure the fulfillment of these requirements by the defined alternatives and ensure the selection of one which will meet the set of requirements at most.
Step 2: Form the HOQ. House of quality is formed through the establishment of links between the requirements and criteria and consists of five main parts (Figure 2). The first part is a list of quality requirements, location requirements in this paper, that reflect the needs which a product or service in general, or location in this paper, must meet. The second part is a vector which refers to the values of the requirements weights, which determine the significance of each location requirement in this paper. The third part consists of qualitative characteristics in general, or criteria for locating the terminal in this paper, that must be taken into account in order to meet the defined requirements. The fourth part is a central matrix of relationships that establishes a connection between the (location) requirements and characteristics (criteria). It indicates the degree of satisfaction of each request in relation to each criterion. The fifth part consists of two vectors, the characteristics weight vector, or in this paper the vector of location criteria weights, indicating the overall level of influence of the criteria over requirements, as well as the normalized characteristics (location criteria) weight vector, which is used in the next phase of the model application as the weights of the criteria for locating the city logistics terminal.

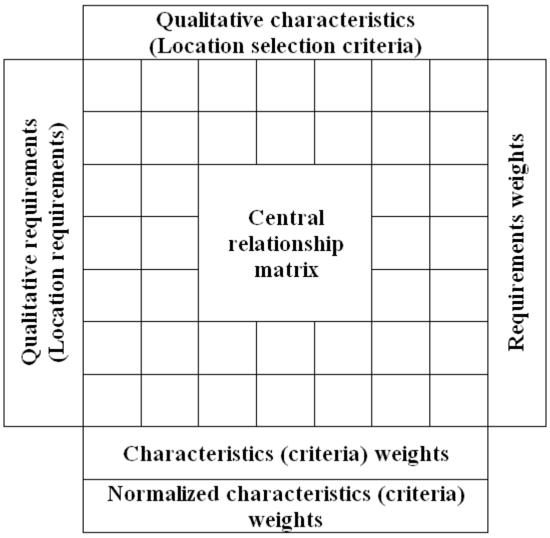


Fig. 2.
HOQ - House of Quality

Step 3: Fill in the central relationship matrix. The matrix is filled out based on the opinion of experts who are involved in the decision making process. The matrix is filled by entering the symbols "■" "◘" and "○", denoting a strong, medium and weak connection between the criteria and requirements, respectively, and indicate the degree of contribution of the criteria to the achievement of the defined requirements. The symbols are then transformed into quantitative values on the scale 4-2-1, i.e. the strong-medium-weak connections are being quantified into the given numeric values.
Step 4: Determine the requirements weights. The weight vector of the (location) requirements is obtained by evaluating the requirements by the experts involved in the decision-making process. In order to determine these weights, more detailed research that would involve various stakeholders (suppliers, customers, carriers, etc.) can be carried out and. The five-point scale shown in Table 1 is used in this paper to determine the requirements weights. In the case of requirements evaluation by the different interest groups or experts, the mean values of their scores are taken as the weights.

Table 1
Five-point scale for the evaluation of the requirements/alternatives

Linguistic assessment	Abbreviation	Numeric value
Weakly preferable/Bad	WP/B	1
Slightly preferable/good	SP/SG	2
Moderately preferable/good	MP/MG	3
Preferable/good	P/G	4
Very preferable/good	VP/VG	5

Step 5: Obtain the criteria weights. The importance of each criterion is calculated as the sum of the weighted evaluations of criteria influence on the implementation of the requirements (the values obtained from the central relationship matrix). Therefore, if *n* location criteria are taken into account in order to meet the *m* location requirements, the importance of each location criterion is obtained by using the equation:

$$w_j = \sum_{i=1}^{m} O_{ij} c_i \tag{1}$$

where w_j is the weight (importance) of criterion *j*, $j=1,2,...,n$, O_{ij} is the quantified evaluation of the relation between location requirement *i* and location criteria *j* from the central relationship matrix, and c_i is the weight of requirement *i*, $i=1,2,...,m$.
Weight values of each criterion are then normalized and such normalized values are then used as the criteria weights in the following part of the model. The following equation is used for normalization:

$$w_j' = w_j / \sum_{j=1}^{n} w_j \tag{2}$$

where w_j' denotes normalized value of the criteria weight.
Step 6: Evaluate the alternatives in relation to the criteria. By using the linguistic assessments, i.e. five-point scale given in Table 1, alternatives, or potential locations in this paper, are evaluated in relation to the criteria.
Step 7: Obtain the final ranking of the alternatives, i.e. potential locations, by applying the VIKOR method (Opricović, 1998).

Step 7.1: For the final ranking of the alternatives by applying the VIKOR method it is first necessary to normalize the quantified evaluations of the alternatives, i.e. potential location, in relation to the defined criteria. Normalization is performed using the following equation:

$$f_{kj} = \frac{x_{kj}}{\sqrt{\sum_{j=1}^{n} x_{kj}}}, k = 1,...,l, j = 1,...,n \quad (3)$$

where x_{kj} is the value of the evaluation of the alternative *k* in relation to the criterion *j*.
Step 7.2: After normalization, the best and the worst values of the criterion function are obtained, i.e. the ideal (f_j^*) and nadir (f_j^-) solutions are determined:

$$f_j^* = \max_k f_{kj}, k = 1,...,l \quad (4)$$

$$f_j^- = \min_k f_{kj}, k = 1,...,l \quad (5)$$

where f_{kj} is the normalized value of the preference of the alternative *k* in relation to criterion *j, j=1,2,...,n..*
Step 7.3 Afterwards, the distances (S_k) of the alternative from the ideal solution, and distances (R_k) from the nadir solution are calculated:

$$S_k = \sum_{i=1}^{n} w_j \left(f_j^{(*} - f_{kj}\right) / \left(f_j^* - f_j^-\right) \quad (6)$$

$$R_k = \max_j \left[w_j \left(f_j^{(*} - f_{kj}\right) / \left(f_j^* - f_j^-\right)\right] \quad (7)$$

Step 7.4: In the end, it is necessary to calculate the VIKOR values Q_k, for *k=1, ..., l*, as follows:

$$Q_k = v\left[\frac{S_k - S^*}{S^- - S^*}\right] + (1-v)\left[\frac{R_k - R^*}{R^- - R^*}\right] \quad (8)$$

where $S^- = \max_k S_k$, $S^* = \min_k S_k$, $R^- = \max_k R_k$, $R^* = \min_k R_k$, and *v* is the weight of the strategy of "maximum group utility". This means that if *v* is greater than 0.5, the index Q_k will strive towards the consensus of the majority, and if it is less than 0.5 the index Q_k will strive towards the negative attitude of the majority. By arranging the Q_k values in the ascending order, the final ranking of the alternatives is obtained.

3. Case study

The proposed evaluation model has been tested for locating city logistics terminal in the city of Belgrade, administrative and economic center of the Republic of Serbia. The problems of logistics in Belgrade have been solved partially and individually, without research and monitoring of the logistic parameters, and concerning the city logistics initiatives, only the ones of regulatory nature have been present. Restrictions are defined, adopted and implemented without the analysis of the situation and their impact (Tadić *et.al*, 2014c).
Logistics systems that support the implementation of goods flows are characterized by great spatial dispersion. Providers of logistics, transportation and distribution services were developing their own systems without adequate cooperation and coordination. For the purpose of improvement the efficiency of logistics activities, particularly in terms of impact on the environment, quality of service and competitiveness of the city and the region, different CL concepts are defined. One solution for the above problems would be the construction of a logistics center for the reception of long haul flows and consolidated delivery to the generator in the city. Given the very significant role of the logistics center in the realization of logistics flows, but also in planning the logistics and transportation systems of the city, it is necessary to determine the optimal location for its construction (Tadić *et.al*, 2012).
The first step of the CLT location selection by applying the proposed model is to define the structural elements of the problem. First, it is necessary to define the location requirements that are defined in this paper based on the literature review and the authors' experiences. Twelve requirements are defined and described in more detail in Table 2.

Table 2
Definitions of the location requirements

Location requirement	Definition
Convenient delivery to the terminal - Re_1	Main roads closeness, good transport infrastructure in the vicinity of the terminal, traffic congestion avoidance etc.
Users proximity - Re_2	The proximity of the users and the existence of adequate infrastructure to enable unhindered access to/from retails and other users of the terminal
Adequate space for development - Re_3	Large enough surface area for the development of all necessary subsystems, additional expansions, good geographical and geological characteristics, etc.
Stable supply of utilities - Re_4	Smooth and stable supply of water, electricity and other consumables, adequate utility infrastructure, availability of utilities, etc.
Preservation of the environment - Re_5	The tendency for the smallest possible influence on the environment (emissions, noise, vibration, etc.) by the processes within the terminal, as

	well as processes outside the terminal but generated by the terminal operations.
Low operating costs - Re_6	Low costs of terminal functioning and its daily activities (transport, storage, keeping inventory, ordering, loading, packaging, etc.).
Security of the goods and preservation of its quality - Re_7	Prevention of unauthorized and illegal usurpation of goods at any stage of goods flow, prevention of good quality degradation as a result of mechanical, weather, biological and other impacts.
Low investment costs - Re_8	Low costs of land acquisition, land development and preparation for construction, obtaining the necessary permits, constructing the facilities and systems, purchasing the equipment, etc.
Fast and reliable distribution - Re_9	Shorter delivery times, frequent deliveries, delivery of the right goods at the right place at the right time, etc.
Quick response to requests - Re_{10}	Ability to respond to the demands and needs of users in a short period of time, the possibility of rapid adaptation to new situations and problem solving.
Available labor force - Re_{11}	Closeness to the parts of the city with a dense population, the possibility of easy and quick access of workers to the terminal, favorable demographic structure.
Application of modern technologies - Re_{12}	Application of modern technologies in the processes of ordering, transportation, warehousing, transshipment, etc., with the aim of better realization of services by all parameters

For achieving the defined requirements, 27 criteria classified into five groups are defined (Tadić et.al, 2012): Land price - C1, Transport costs - C2, Users proximity - C3, Economic growth - C4, Traffic congestion - C5, Construction costs - C6 (Economic criteria); Transport infrastructure already built - C7, Multimodality - C8, Degree of facility establishment - C9, Utility infrastructure - C10, Expansion possibilities - C11, Location availability - C12, Safety of the location - C13 (Infrastructural criteria); Land ownership - C14, Populated areas proximity - C15, Compliance with spatial plans - C16, Compliance with regulations - C17, Traffic safety - C18 (Socio-political criteria); Weather conditions - C19, Geological conditions - C20, Hydrological conditions - C21, Topographic conditions - C22 (Natural criteria); Air pollution - C23, Noise and vibration emission - C24, Natural environment disturbance - C25, Influences of environment on goods - C26, Visual fitness into the environment - C27 (Ecological criteria). The evaluation criteria are defined on the basis of authors' experience and literature review. The following CLT potential locations (alternatives) are evaluated on the basys of the defined criteria (Tadić *et.al*, 2012): Pančevački rit - A_1, Luka "Beograd" - A_2, Ada Huja - A_3, Batajnica - A_4, Brodogradilište - A_5, Rakovica - A_6 and Kumodraž - A_7. Potential locations are defined by "Master plan of Belgrade 2021" as locations planned for the establishment of logistics facilities.

After defining the structural elements of the problem, the HOQ is formed in which the symbols ("■" "◘" and "○") represent the experts' evaluations of the importance of defined criteria for the achievement of the defined requirements. By applying linguistic assessments shown in Table 1, the experts also evaluated the significance of the location requirements. House of quality is shown in Table 3.

Table 3

HOQ for obtaining the criteria weights in the process of locating the CLT

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	**Req. import.**
Re_1	○	■	◘		■		■	■				■			◘		◘	◘					○	○				VP
Re_2	○	■	■		◘		◘	◘				■			■			○										P
Re_3	◘					■			◘	◘	■			■		■	◘			◘	◘	◘					○	MP
Re_4	◘					◘			○	■				○	■	■				○	○	○						SP
Re_5			◘		■		○	◘		○					◘	○	◘	◘	○	○	○	○	■	■	■		■	SP
Re_6		■	■		◘			◘				■						◘					○	○				VP
Re_7													■				◘	■	○	○						○		P
Re_8	■					■	■	◘	◘	◘				■		◘	○		◘	◘	◘	◘			○		○	P
Re_9		■	■		■		■					■			◘			○										P
Re_{10}		■	■		■		◘	◘				■																MP
Re_{11}				■											◘													WP
Re_{12}		◘		◘		○		■					◘					◘					◘	◘	◘		○	MP
	w_j, j=1,2,...,n																											
	w_j', j=1,2,...,n																											

Based on the quantified values from the HOQ and by applying the equation (1), criteria weights are obtained (w_j), which are then by applying the equation (2) normalized and these normalized criteria weights (w_j') are shown in Table 4. Afterwards, alternatives are evaluated in relation to the defined criteria, by the experts, using a five-point scale given in table 1. These evaluations are also shown in table 4.

Table 4
Alternatives evaluations in relation to criteria

	w_j'	A_1	A_2	A_3	A_4	A_5	A_6	A_7
C_1	0,036	B	VG	MG	G	SG	VG	B
C_2	0,093	VG	MG	VG	MG	B	SG	G
C_3	0,080	MG	SG	G	G	B	G	SG
C_4	0,010	SG	MG	SG	VG	VG	SG	G
C_5	0,076	MG	G	MG	MG	SG	MG	MG
C_6	0,036	B	G	B	B	G	B	SG
C_7	0,070	B	G	SG	SG	MG	B	B
C_8	0,070	B	VG	MG	G	SG	VG	B
C_9	0,016	VG	MG	VG	MG	B	SG	G
C_{10}	0,025	MG	SG	G	G	B	G	SG
C_{11}	0,012	SG	MG	SG	VG	VG	SG	G
C_{12}	0,087	MG	G	MG	MG	SG	MG	MG
C_{13}	0,023	B	G	B	B	G	B	SG
C_{14}	0,031	B	G	SG	SG	MG	B	B
C_{15}	0,049	B	VG	MG	G	SG	VG	B
C_{16}	0,031	VG	MG	VG	MG	B	SG	G
C_{17}	0,033	MG	SG	G	G	B	G	SG
C_{18}	0,056	SG	MG	SG	VG	VG	SG	G
C_{19}	0,014	MG	G	MG	MG	SG	MG	MG
C_{20}	0,023	B	G	B	B	G	B	SG
C_{21}	0,019	B	G	SG	SG	MG	B	B
C_{22}	0,019	B	VG	MG	G	SG	VG	B
C_{23}	0,025	VG	MG	VG	MG	B	SG	G
C_{24}	0,025	MG	SG	G	G	B	G	SG
C_{25}	0,019	SG	MG	SG	VG	VG	SG	G
C_{26}	0,004	MG	G	MG	MG	SG	MG	MG
C_{27}	0,019	B	G	B	B	G	B	SG

Evaluations of alternatives in relation to the criteria are converted into numerical values, which are then normalized by applying the equation (3). Based on the obtained values the ideal (f_j^*) and nadir (f_j^-) solutions are defined by using the equations (4) and (5). Afterwards, the distances of the alternatives from the ideal (S_k) and nadir solutions (R_k) are calculated using the equations (6) and (7). In the end, VIKOR values Q_k are obtained by applying the equation (8). For obtaining the Q_k values, the value of v=0.5 is used in this paper. Values of S_k, R_k, Q_k, as well as the final ranking of the alternatives are shown in Table 5. It can be seen from the table that the alternative A_4 - Batajnica is selected as being the most suitable location for city logistics terminal.

Table 5
Final ranking of the CLT potential locations

	S_k	R_k	Q_k	Rank
Pančevački rit - A_1	0.610	0.087	0.799	5
Luka "Beograd" - A_2	0.517	0.076	0.555	3
Ada Huja - A_3	0.611	0.093	0.887	6
Batajnica - A_4	0.251	0.062	0.065	1
Brodogradilište - A_5	0.539	0.057	0.310	2
Rakovica - A_6	0.716	0.087	0.913	7
Kumodraž - A_7	0.692	0.070	0.656	4

4. Conclusion

Locating the CLT is a long-term problem which must be addressed with a lot of attention as the selection of the appropriate location has a significant impact on the participants and subsystems of the city logistics. As the process of locating the CLT requires the participation of various stakeholders: local authorities, potential operators, trade associations, local logistics companies, potential users, etc., it is necessary to take into account their requirements and needs that can be met only by defining multiple location criteria, based on which the location that will be in accordance with the defined requirements can be selected. Accordingly, this paper proposes a model that combines QFD and VIKOR methods, whereby the QFD method is used to establish the connection between the location requirements and location criteria, as well as for obtaining the criteria weights, while VIKOR method is used for evaluating alternatives in relation to the defined criteria and selecting the most suitable alternative, i.e. CLT potential location. The applicability of the proposed model is demonstrated on the real case study of selecting the CLT location in the city of Belgrade. In the future research, the described problem and defined model could also be solved in the fuzzy environment, especially if we take into account that the assessment of the connection between the requirements and criteria, the importance of the requirements, as well as the evaluations of the alternative in relation to the criteria, are established based on the evaluations of the decision makers, who often give incomplete and vague judgments. In addition, the evaluations could be performed by the decision makers as direct representatives of various stakeholders (and for the unification of their evaluations and achievement of the consensus, the model could be extended with some additional method).

References

Awasthi, A.; Chauhan, S.S.; Goyal, S.K. 2011. A multi-criteria decision making approach for location planning for urban distribution centers under uncertainty, *Mathematical and Computer Modelling,* 53: 98-109.

Caterino, N.; Iervolino, I.; Manfredi, G.; Cosenza, E. 2008. A comparative analysis of decision making methods for the seismic retrofit of rc buildings. *The 14th World Conference on Earthquake Engineering*, October 12-17, 2008, Beijing, China.

Chan, L.K.; Wu, M.L. 2002. Quality function deployment: a literature review, *Eur. J. Oper. Res*, 143(3): 463-497.

Guyon, O.; Absi, N.; Feillet, D.; Garaix, T. 2012. A modeling approach for locating logistics platforms for fast parcels delivery in urban areas. *The Sixth International Conference on City Logistics*. *Procedia Social and Behavioral Sciences,* 39: 360-368.

Hwang, C.L.; Yoon, K.S. 1981. *Multiple attribute decision making: Method and applications*. NY: Springer.

Master Plan of Belgrade 2021. Available from Internet: < http://www.beograd.rs/cir/beoinfo/201126-master-plan-of-belgrade-to-2021/ >.

Mizuno, S.; Akao, Y. 1994. *The Customer-Driven Approach to Quality Planning and Development*. Asian Productivity Organization, Tokyo, Japan.

O'Connor, P.D.T. 1990. *Handbook of Quality Management*, D. Lock (ed.), Gower Press.

Opricovic, S.; Tzeng, G.H. 2004. Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS, *European Journal of Operational Research,* 156(2): 445-455.

Opricovic, S. 1998. *Multi-criteria optimization of civil engineering systems*. Belgrade: Faculty of Civil Engineering.

Ren, Y.; Xing, T.; Chen, X.; Chai, X. 2011. *Fuzzy Comprehensive Evaluation of Location Plan of City Distribution Center*. Singapore, Elsevier.

Shahin, A. 2008. Quality Function Deployment: A Comprehensive Review. Total Quality Management-Contemporary Perspectives and Cases, Andhra Pradesh: ICFAI University Press.

Šolc, M. 2013. QFD Method - One of the Tools of Quality Management. *Electronic International Interdisciplinary Conference*, September 2-6, 2013.

Sularto, L.; Wardoyo; Yunitasari, T. 2015. User Requirements Analysis for Restaurant POS and Accounting Application Using Quality Function Deployment. *Procedia - Social and Behavioral Sciences*, 169: 266-280.

Tadić, S.; Zečević, S. 2016. *Modeliranje koncepcija city logistike*, Saobraćajni fakultet, Beograd.

Tadić, S. 2014. *Modeliranje performansi integrisanih city logističkih sistema*. Saobraćajni fakultet, Univerzitet u Beogradu, PhD.

Tadić, S.; Zečević, S.; Krstić, M. 2014a. Inicijative city logistike u cilju poboljšanja održivosti promenom konteksta urbane sredine, *Tehnika,* 61(5): 834-843.

Tadić, S.; Zečević, S.; Krstić, M. 2014b. Inicijative city logistike u cilju poboljšanja održivosti unutar postojećeg konteksta urbane sredine, *Tehnika,* 61(3): 487-495.

Tadić, S.; Zečević, S.; Krstić, M. 2014c. A novel hybrid MCDM model based on fuzzy DEMATEL, fuzzy ANP and fuzzy VIKOR for city logistics concept selection, *Expert Systems with Applications,* 41(18): 8112-8128.

Tadić, S.; Zečević, S.; Krstić, M. 2012. City logistics terminal location selection using combined fuzzy AHP and fuzzy TOPSIS analysis. In *Proceedings of the International conference on traffic and transport engineering, ICTTE*, Scientific Research Center Ltd. Belgrade, Belgrade, Serbia, 345-358.

Tsai, W.H.; Chou, W.C.; Leu, J.D. 2011. An effectiveness evaluation model for the web-based marketing of the airline industry, *Expert Syst. Appl.,* 38(12): 15499-15516.

CONSIGNMENT STOCK CONCEPT IN THE CZECH REPUBLIC

Petra Vrbová[1], Václav Cempírek[2]
[1] *Faculty of Administration and Economy, University of Pardubice, Pardubice, Czech Republic*
[2] *Jan Perner´s Transportation faculty, University of Pardubice, Pardubice, Czech Republic*

Abstract: The concept of Consignment Stock is a very important logistic technique for short-term asset management as it is a completely innovative approach. This concept is crucial for helping manage inventories in which the supplier furnishes the inventory and maintains a stock of material in the buyer´s possession. This paper deals mainly with analysis finding of usage and share of the Consignment Stock concept usage in the Czech Republic and defining obstacles and gains before/during/after the implementation of Consignment Stockage. The analysis is based on a quantitative survey held in the Czech Republic.

Keywords: consignment stock concept, just-in-time, inventory management, vendor inventory management.

1. Introduction

The Consignment Stock (CS) inventory policy is becoming an important strategy that companies adopt to face new manufacturing and supply chain management challenges. A CS policy implies great collaboration between the buyer and supplier, pushing them towards a complete exchange of information and a consistent sharing of management risks (De Matta, 2014). The CS policy is already widespread in a number of industrial realities and it is obtaining raised consensus in both small and large contexts, since it offers a partial solution to the 'cycle time reduction' problem and avoids any shortage of materials through enhanced communication between suppliers and buyers. The technique in fact allows partners, the vendor and the buyer, to reduce management costs and increase their flexibility. In particular, the buyer virtually removes the procurement lead time, since the responsibility of the replenishment lies completely with the vendor, who keeps a stock of its property at the buyer's plant: the buyer uses the stock of materials according to his daily production requirements. Outsourcing of materials can easily incorporate the CS policy to enhance supply chain operations (Battini, 2010). CS is a logistic technique in which the vendor, instead of the buyer, is in charge of managing the buyer's inventory and triggering replenishment orders. This makes possible a partial suppression of the vendor's warehouse, which can be replaced by that of the buyer (Braglia, 2013). In particular, the buyer virtually removes the procurement lead time, since the responsibility of the replenishment lies completely with the vendor, who keeps a stock of its property at buyer's plant: the buyer uses the stock materials according to his daily production requirements (Abdel-Malek, Kullpattaranirun, Nathavanij, 2005). Consignment Stock (CS) is an innovative approach to supply and stock management, based on a strong and continuous collaboration between vendor and buyer to create a "win-win" situation, where both partners have equal gains (Battini, 2010). There is an obvious advantage for buyers. They have available stock and they can pay later for that. For sellers there is a very high certainty of supply and demand turnover when the stocks are with customers and the sale is almost guaranteed. And also they save space in their own warehouses. It also saves time to every part of the deal, because stock is being ordered by system which often uses min max method.

2. Basic elements of consignment stock

CS is a logistic technique in which the vendor, instead of the buyer, is in charge of managing the buyer's inventory and triggering replenishment orders. This makes possible a partial suppression of the vendor's warehouse, which can be replaced by that of the buyer. Consequently, it is possible to minimize both the ordering and the stock holding costs of the buyer, because materials formally owned by the vendor can be collected (that is, purchased) by the buyer only upon demand. On the other hand, the vendor gets visibility regarding the customer's demand and can use this precious information to schedule production and replenishment orders in an optimal way (Braglia,2013). In a CS policy, the buyer incurs stocking costs, since the materials are located in the buyer's plant, but does not sustain financing cost, since the item is purchased only when needed. In fact, since the item is formally purchased upon demand, the vendor sustains the financial costs of the capital immobilized until that moment. The vendor also receives a number of advantages. First of all, the average stock is reduced leaving more available space for stocking new items. Moreover, the vendor increases his production management flexibility since he is no longer constricted by consecutive close orders. For these reasons, a CS policy aims to reduce management and logistic complexity of the stocks and to ensure at the same time a constant availability of materials in order to eliminate stock-out risks. (Battini, 2010).
With regard to the basic description of the Consignment Stock concept, it is explained in Figure 1 below. Firstly, the Consignment stock itself is housed at buyers´ plants. Further, the buyer consumes delivered goods according to the daily production request. The information surrounding daily consumption data is exchanged with supplier. Additionally, vendor delivers the needed material according to the data exchange with the buyer enabling production planning. Finally, in the last step of the cycle, consignment stock refilling is performed by the vendor, including stock data update.

[1] Corresponding author: pe.vrbova@gmail.com

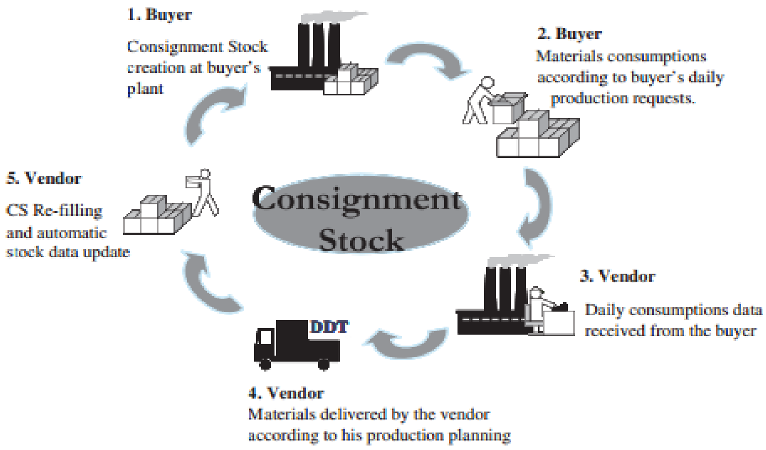


Fig. 1.
Consignment stock concept
Source: (Battini,2010)

Production and delivery of a schedule determined so as to minimize the total annual cost of the entire supply chain. Whenever something is produced, it is sent to the seller, who then sells the products in individual doses. Implementation of the consignment warehouse in cooperation seller and the buyer must be a fixed order. In order to avoid the production of the additional costs, should each machine to produce the maximum capacity (Braglia, 2013).

2.1. Consignment stock MIN a MAX concept

Supplier is responsible for keeping the buyer's inventory between a maximum (S) and a minimum level (s) and he also supports any additional cost due to stock-outs if his stock management strategy is not suitable to assure the required service level (Braglia,2013). In CS model a vendor can freely decide interval and volume of replenishment orders. The only requirement is that inventory in customer's warehouse stays between a minimum required level s and a maximum level S. Both s and S are agreed in a contract between vendor and customer (Valentini, Zavanella, 2003). The following Table 1. explains supplier's and customer's interests in stock level setting.

Table 1
Stock level related motivation for the supplier and the customer

Desired (s, S) and related motivation for supplier and the company		
	***s* level**	***S* level**
Supplier	↓ Keep as low as possible It represents a capital "frozen" in the company´s warehouse, which determines as opportunity cost	↑ Keep as high as possible It consists in a space offered by company to stock products, thus freeing space in own warehouses. Consequently, production flexibility may be increased
Company	↑ Keep as high as possible It is a sort of safety stock which enables a higher service level, whereas its economic burden is borne by supplier	↓ Keep as close as possible to *s* level There is a need for limiting the space occupied by the products and for reducing the problems linked to their management and handling

Source: (Valentini, Zavanella, 2003)

In Table 1 s represents the minimum inventory level allowed in the CS contract. A Supplier's motivation is to negotiate the s level as low as possible. The lower the s level is the less of a supplier's capital is potentially tied in the goods. In proportion, high s level means high safety stock for the customer. High s level is customer's advantage. S stands for the maximum allowed inventory level. While the supplier prefers a high S level to increase his or her operational flexibility, an S level close to s level is preferable for the customer. A Customer's total storage costs rise when more goods are stored in his or her premises (Rauvola, 2010). CS is preferably used for products characterized by constant consumption. Nonstandard products and prototypes are not to be included in CS programs (Valentini, Zavanella, 2003).

2.2. Benefits of Consignment stock concept

According to Graham (2015), first, the primary benefit that can be derived from a consignment agreement is that it allows the consignee to save money on inventory costs. As the consignee, you do not need to put money on the goods that you sell. You pay the consignor only after you have sold the merchandise. This could mean improved cash flow on the part of the consignee. Next, consignment can actually save you time because you do not have to wait for new inventory every time you run out of stock. Typically, the person or company that consigned the goods will automatically replenish your inventory right after you sell some or all of the consigned goods. It is in the best interest of the consignor to keep the agent well-supplied. Third, a consignment agreement is more convenient compared to a drop shipping arrangement where the retailer only takes orders and does not hold any inventory from the supplier. The consignee will have the merchandise on hand, easily accessible and ready for sale. Moreover, the consignee does not have to worry about goods running out of stock indefinitely, as resupplying the inventory happens regularly under a consignment setup (Graham, 2015).

Piasecky (2000) claims that the key benefit to the customer should be obvious; he does not have to tie up his capital in inventory. This does not mean that there are no inventory carrying costs for the customer; he does still incur costs related to storing and managing the inventory. So what's in it for the supplier? This is where the benefits may not be so obvious - or may not even exist. The supplier has the product or group of products for which believe they will sell and fall into the hands of end users mainly. The trick is that before we get products for end consumers, we need to get to the stock to the retailer. Traders are hesitant whether or not to store products because they do not have complete confidence in the suppliers do not want to invest money and risk to keep them in stock remained something that is not for sale (Lee, 2005).

Table 2
Consignment stock policy: benefits

Benefits for the buyer	Benefits for the vendor
1 Materials always on-hand	1 Optimization of transport
2 Reduced management costs	2 Optimization of production lot sizes
3 Procurement leads times drastically reduced (ideally eliminated)	3 Information on real consumption available (i.e., on-line data update or EDI interface)
4 Production mix more flexible	4 More space available
5 Immediate payment only of material quantities used daily	5 Long term relationship

Source: (Battini, 2010)

In Table 2, there are specified particular benefits separated from both a supplier's and a customer's perspective. With regard to benefits for the vendor, Battini (2010) deals mostly about the optimization of transport, of production sizes due to the fact that the entire planning of transport and lot sizes is to the domain of the vendor in accordance with real consumption data availability, as provided by the buyer. Furthermore, there are additional benefits for the vendor such as increased space availability and a long term contractual relationship. From the buyer's end, the main advantages are generally: materials are always on hand despite reduced management costs covered by vendor; procurement lead times are drastically reduced in case of optimal deliveries from vendor; the production mix is more flexible and payments are due only in the case of material quantities which are consumed.

2.3. Responsibility of vendor and buyer

Increasingly, competition has forced companies to seek stronger cooperation and strengthen the relations with its suppliers. One example of such cooperation is cooperation between two partners which will help to minimize costs and maximize profits of the entire system. Many researches showed that joint decisions business partners lead to the effective functioning before deciding if every man for himself within the same organization (Lee, 2005). These responsibilities affect the costs that each one of the players incurs in the future. Table 3 distinguishes the major responsibilities of Vendor and Buyer according to Zahran (2015).

Table 3
Summary of the responsibilities for the vendor and the buyer for consignment stock agreements

Responsibility	Vendor	Buyer
Product ownership	✓	
Physical loss, damage, theft, or defect		✓
Unused, unsold, or expired products	✓	
Inspection of delivered items		✓
Periodic inventory review, or audit	✓	✓
Inventory management		✓
Reporting, and order initiation		✓
Product pricing	✓	✓
Stock level management, and usage invoice	✓	
Payment by the due date		✓
Storage space requirement		✓

Source: (Zahran, 2015)

2.4. Risks associated to Consignment stock concept

Consignment stock may become disadvantageous if it brings about discrepancies in the records of both vendor and buyer. Table 3 above might refer also to risks associated to Consignment stock concept. Since for product ownership, it is vendor responsibility, he/she also has to deal with unused, unsold or expired products that might cause very high costs. The party supplying the stock faces the biggest risks under a consignment agreement. For one, the consignor will not receive any money until part or all of the consigned stock has been sold. In effect, the consignor's cash flow may suffer as more money is spent on manufacturing the goods, while cash coming in may be too slow to cover subsequent production runs. Next, the consignor may be exposed to higher product returns if the agents or consignees simply allow the goods to rot or become damaged in warehouses. After all, the consignee does not have any money invested in the consigned merchandise. Without a good profit sharing agreement, the consignee may not be too keen on pushing the consignor's products in the market. In addition, since resupplying or restocking the consignment inventory is done regularly, there is a risk of overstocking or duplicate inventories. This could be detrimental for both the consignor, who would have more goods sitting idly in the agent's warehouse, and for the consignee, who may spend more on inventory storage costs. Lastly, the record keeping systems of the party consigning the goods and the retailer or agent are not always the same (Graham, 2015). On the other hand, since buyer is responsible for storage of the materials, physical loss, damage, theft or defect, there is a huge responsibility of buyer and it is required. To provide inspection of delivered items by buyer as well. Buyer might avoid potential risks by periodic inventory review or audits. For the consignee, any misplaced item could mean paying for something that has not generated a profit. Meanwhile, inconsistencies on the consignor's side could lead to lost merchandise (Graham, 2015).

3. Methodology

There exists a plethora of research, studies, analyses, and formulas dealing with Consignment Stock, albeit mainly from theoretical point of view. By the way of contrast, there is little that is known about real usage - in terms of a practical adoption. It is therefore the main objective of this paper to specify and find out the share of the Consignment Stock concept usage in the Czech Republic and define obstacles and gains before/during/after the Consignment Stock implementation.

For the purpose of this paper, a quantitative survey was held in the Czech Republic as the main data collection source. The research was held in the period between March and May 2016 and obtained in the Czech Republic. A field survey was used to investigate the research questions and a structured questionnaire was utilized as the main data collection. Respondents/companies were selected both randomly and according to companies sampled in previous researches (71 companies). Companies were contacted as sampled from various industries and of different sizes and annual sales, in order to complete the questionnaire. Out of 118 companies addressed in various areas of business, 33 companies did not reply or refused to participate. Therefore, 85 replies were compiled.

Table 4
Respondents' overview

Industry	Total
Auto parts industry	6
Building industry	3
Ceramic industry	3
Chemical products	4
Drug manufacturing	5
Electronic industry	9
Food manufacturing	5
Metal manufacturing.	8
Paper industry	4
Plastic industry	7
Retail industry	8
Service industry	3
Steel manufacturing	8
Textile manufacturing	6
Transportation industry.	3
Wood processing industry.	3
Total	85

Source: (Author)

4. Key results

According to the research, a number of major advantages and disadvantages of Consignment stock concept adoption in the Czech Republic were identified. We were able to distinguish all the results below according to the buyer´s and supplier's point of view, separately.

4.1. Advantages of CS concept from the supplier's point of view

Table 5 demonstrates the main advantages of CS concept adoption from the supplier´s point of view. The major advantage can be identified as increased flexibility in deliveries (49%) as confirmed by almost half of respondents. Another advantage was determined to be the optimization of production sizes (25%). Due to the fact that each delivery is generally paid for following the actual consumption and consequently paid on a regular basis on contracted credit terms that may defer the capital expenditure for up to and over 3 months . One fifth of respondents also agreed that there is a huge advantage found in the diminished responsibility and time spent within orders and deliveries (20%).

Table 5
Advantages of CS concept from the supplier's point of view

Advantage	Nr. answers	% of answers
Optimization of production sizes	**25%**	21
More flexible deliveries	**49%**	42
Less responsibility and time /effort spent within orders and deliveries	**20%**	17
Others	6%	5
Total	100%	85

Source: (Author)

4.2. Advantages from the buyer`s point of view

Table 6 shows the most significant advantages of the Consignment Stock concept from the buyer’s point of view. Buyers find the following aspects as the most pervasive advantages of Consignment Stockage in almost equal measure – reducing the cost of business capital (18%), flexible response to a customer´s requests (15%), continuous availability of goods for customer (16%) and continuity of the production process (14%).

Table 6
Advantages of CS concept from the buyer`s point of view

Advantage	Nr. answers	% of answers
Continuity of the production process	12	**14%**
Flexible response to customer`s requests	13	**15%**
Reducing the cost of business capital	15	**18%**
Reduction of transportation and administrative costs	9	11%
Continuous availability of the goods for customer	14	**16%**
Customer payments after a real mat. consumption	11	13%
Inventory cost reduction and new form of production planning	5	6%
New way of partnership between customer and supplier	5	6%
Others	1	1%
Total	85	100%

Source: (Author)

4.3. Disadvantages from the supplier`s point of view

Table 7 shows the most significant disadvantages of CS from the supplier`s point of view. More than one third of all the respondents agreed, that the crucial disadvantage is the fact that suppliers need to deal with high bound capital in stock costs (35%) reserved for buyers. Furthermore, it is of great importance for suppliers to bear in mind risks and disadvantages associated with the need of regular inventory checking (22%), maintaining warehoused stock levels (20%), the entire responsibility for planning and delivery, etc. (21%).

Table 7

Disadvantages of CS concept from the supplier`s point of view

Disadvantage	Nr. answers	% of answers
High bound capital in stocks	30	**35%**
Keep a stock in warehouse	17	**20%**
Entire responsibility for production planning, delivery, etc.	18	**21%**
Regular inventory checking	19	**22%**
Others	1	1%
Total	85	100%

Source: (Author)

4.4. Disadvantages from buyers´ point of view

Table 8 shows the most significant disadvantages of CS from the buyer`s perspective. Buyers as respondents of this survey are mostly worried about the risks inherent with supplier reliability (40%). Trust, reliability and proper partnership are more than required in this kind of cooperation, due to the fact that in the event of low supplier reliability and delays, production stoppage and additional costs or penalties might ensue. More than a third of buyers listed as disadvantageous cases of claims and returns of goods (30%) as acquired goods would have already been invoiced and similarly, less responsibility for (and therefore, control over) deliveries (26%) which relates to the aforementioned risk of supplier reliability.

Table 8

Disadvantages of CS concept from the buyers´ point of view

Disadvantage	Nr. answers	% of answers
Risk of supplier reliability	34	**40%**
Claims, returned goods	26	**31%**
Less responsibility for deliveries	22	**26%**
Others	3	4%
Total	85	100%

Source: (Author)

5. Discussion

The concept of Consignment Stock is an innovative approach, requiring an established and solid cooperation and partnership between both parties to the transaction. Given the vast amount of research dealing with the mainly theoretical concept of Consignment Stock, the main aim of this paper was to discover practical advantages and disadvantages of the consignment stock concept from both the supplier's and buyer's perspective.

With regard to the supplier´s benefits, it has been determined that mainly the advantages listed centre around optimization of production sizes, increased flexibility in deliveries (more frequent and smaller deliveries) and less responsibility and time/effort spent within the ordering and delivery phases of the transaction (since the supplier is fully responsible for all these actions). From a buyer´s perspective, is the main benefits identified revolve around the reduction of the cost of operational capital, continuous availability of goods, and increased flexibility in responses to the customer´s request.

In determining supplier disadvantages, it was discovered that these mainly centre around the high bound capital in stocks (supplier invests capital into both goods in the consignment stock and also goods within their internal production and warehouse in order to be ready to supply once the reorder levels in the buyers´ consignment stock are reached); regular inventory checking, and the entire responsibility for production planning and deliveries. For buyers, the main disadvantages identified, mainly centre around the risks inherent with supplier reliability (in the event of which major additional costs could arise due to cessation of production, express transport costs, delays etc.), claims and returned goods (with the ensuing bureaucracy and time wastages in identifying goods that would have already been invoiced and considered as consumed), less responsibility for (and therefore control over) deliveries.

6. Conclusion

This article mainly focuses on analysis finding of usage and definition of obstacles and gains before/during/after the Consignment Stock implementation. For the purpose of this paper, a quantitative survey held in the Czech Republic was used as the main method of data collection, with a deeper focus on identifying advantages and disadvantages of the Consignment Stock concept itself for both suppliers and buyers. This paper is considered as just a part of the complete research dealing with risks related to the Consignment Stock concept implementation. This work helped to identify weak gaps that might be found as potential risks to avoid for the future implementation of Consignment Stock. Future work will focus on finding out what difficulties, obstacles and risks were found before, during and after the consignment stock implementation.

References

Abdel-Malek, L.; Kullpattaranirun, T.; Nathavanij, S. 2005. A framework for comparing outsourcing strategies in multi-layered supply chains, *International of Production Economics*, 97(3): 318-328.

Battini, D. 2010. Consignment stock inventory model in an integrated supply chain, *International Journal of Production Research*, 48(2): 477-500.

Battini, D. 2010. Consignment stock inventory policy: methodological framework and model, *International Journal of Production Research*, 48(7): 2055-2079.

Battini, D.; Gunasekaran, A.; Faccio, M.; Persona, A.; Sgarbossa, F. 2009. Consignment stock inventory model in an integrated supply chain, *International Journal of Production Research*, 48(2): 477-500.

Braglia, M. 2013. Consignment stock theory with a fixed batch manufacturing process, *International Journal of Production Research*, 51(8): 2377-2398.

Braglia, M.; Castellano, D.; Frosolini, M. 2014. Safety stock management in single vendor-single buyer problem under VMI with consignment stock agreement, *International of Production Economics*, 154: 16-31.

Braglia, M.; Gabbrielli, R.; Zammori, F. 2013. Consignment stock theory with a fixed batch manufacturing process, *International Journal of Production Research*, 51(8):2377-2398.

De Matta, R.; Lowe, J.T.; Zhang, D. 2014. Consignment or wholesale: Retailer and supplier preferences and incentives for compromise, *Omega*, 49: 93-106.

Graham, S. 2015. Effective and efficient use of safety or buffer stock, *Operations Management*, 38(5): 27-31.

Lee, C.C. 2005. Production, Manufacturing and Logistics: Who should control inventory in a supply chain?, *European Journal of Operational Research*, 164(1): 158-172.

Piasecki, D. 2000. Consignment Inventory: What is it and When Does It Make Sense to Use It. Available from internet: <http://www.inventoryops.com/ConsignmentInventory.htm>.

Rauvola, E. 2010. *Consignment stock in group trade: Sales and Delivery Processes of Bayer Schering Pharma Oy*, Turku University of applied Sciences, Turkey.

Sitompul, C. 2008. Safety stock placement problem in capacitated supply chains, *International Journal of Production Research*, 46(17): 4709-4727.

Valentini, G.; Zavanella, L. 2003. The consignment stock of inventories: Industrial case and performance analysis, *International of Production Economics*, 81-82: 215-224.

Zahran, S.K. 2015. Payment schemes for a two-level consignment stock supply chain system, *Computers*, 87: 491-505.

PRACTICAL APPLICATION OF THE METHODOLOGY FOR DETERMINING THE PERFORMANCE OF A COMBINED TRANSPORT TERMINAL

Ján Ližbetin[1], Ondrej Stopka[2]
[1,2] The Institute of Technology and Business in České Budějovice, Faculty of Technology, České Budějovice, Czech Republic

Abstract: This paper deals with the issue of overall performance of combined transport terminals. It is important to take into account the "compatibility" and how it ties with other elements of the terminal so that the transition of the intermodal transport unit over individual elements of the combined transport terminal is as smooth as possible. Practical application of the methodology was verified in the Prerov combined transport terminal which lies on the main railway line number 330 Prerov – Breclav, which is part of the second rail transit corridor in Czech Republic. The methodology consists of the optimization of all equipment and components performance in combined transport terminals comprising for example the handling equipment, reloading tracks, storage and reloading areas.

Keywords: combined transport terminals, handling equipment, optimization, storage, reloading, intermodal transport.

1. Introduction

Combined Transport Terminal (CTT) is the most important part of a combined transport infrastructure where various modes of transport come together (Fedorko et al., 2014), (Zając and Świeboda, 2015). It represents the point of change of the type of transport (rail, water, road) when handling intermodal transport units (large container, swap body, road trailer or entire articulated vehicle) and allows for cooperation of all concerned modes of transport (Stopka et al., 2014a), (Rogić et al., 2010).
The overall performance of the combined transport terminal is affected by the performance or by the parameters of the various elements of its internal infrastructure. Each element of the terminal should be designed to minimize the total time it takes to service road articulated vehicles and train units. It is important to take into account the "compatibility" and how it ties with other elements of the terminal so that the reloading the intermodal transport unit (thereafter referred to as ITU) over individual elements of the CTT is as smooth as possible. Practical application of the methodology was verified in the CTT Prerov. (Lizbetin, 2013), (Krile et al., 2015), (Siroky et al., 2010).

2. Performance Analysis of the Original Conditions in CTT Prerov

The combined transport terminal Prerov lies on the main railway line number 330 Prerov - Breclav which is a part of the second rail transit corridor. Near the CTT is the main road I/47 and I/55. There are plans to build the motorway D1 in the future (Kliestik, 2013), (Kubasakova et al., 2014).
At the time of the analysis (2013), the terminal had one single gantry bridge crane on tires PD 38 which worked as a principal means of handling and stacking and one side forklift truck BP 25, which worked as complementary. Both handling devices are able to handle large ISO containers only (Tadić et al., 2015). The storage area of the CTT is 2500 m^2. The usable length of the reloading tracks is 377 and 285 metres.

2.1. Performance of Handling Equipment

The performance of the handling equipment will be calculated separately for the crane and for the forklift truck. The parameters of the handling equipment are provided in Table 1.

Table 1
Technical parameters of the handling equipment in CTT Prerov

PD 38		BP 25	
speed	80 m/min	speed	300 m/min
span	12 m	weight	35 t
weight	38 t	lift height	8.125 m
lift height	8.5 m	turning radius	10.5 m
time for one loading operation	3 – 4 min	time for one loading operation	6 - 7 min

Source: authors
The time required for the loading operation of one ITU (large container - hereafter referred to as LC) located in the immediate vicinity of the crane is three minutes - T_1 (see Table 1). To calculate the handling the outermost

[1] Corresponding author: lizbetin@mail.vstecb.cz

ITU, we must first know the layout of the area under the crane which consists of one reloading track, one lane for articulated vehicles and one storage area (Siroky, 2011). Clearance of the crane allows stacking the LCs into three layers. Time T_2 is then calculated as follows:

$$T_2 = t_d + n_v * T_1$$
$$T_2 = 4.71 + 3 * 3 = 13.71\ min \tag{1}$$

Next, we determine the average handling time for one handling T_A:

$$T_A = \frac{T_1 + T_2}{2} = \frac{3 + 13.71}{2} = 8.36\ min \tag{2}$$

The calculations show that the hourly performance of the crane PD 38 is 7 handling operations. The shift performance of the crane (if the working day is 8,5 hours) is calculated as follows:

$$Q_O = \frac{T_{shifts} - (t_{breaks} + t_{waitingtime})}{T_A} = \frac{8.5 - (0.5 + 2 * 0.25)}{8.36} * 60 \cong 53\ LCs \tag{3}$$

The one side forklift truck BP 25 also allows stacking the containers in three layers in one row. The container can be handled on one side only. Reloading the container is therefore possible either to an articulated vehicle (travelling next to the vehicle), or by turning the car with the container at the specified location and unloading the container on the opposite side. Only the second option is possible in CTT Prerov. For these reasons, the time for one loading operation is extended by the necessary moves to places where it is possible to load or unload of LCs on to or off articulated vehicles or places that enable turning the vehicle.

$$T_1 = 7\ min$$
$$T_2 = t_d + n_v * T_1 = 1.26 + 3 * 7 = 22.26\ min$$
$$T_A = \frac{T_1 + T_2}{2} = \frac{7 + 22.26}{2} = 14.63\ min \tag{4}$$

The calculations show that the hourly performance of the forklift truck is 4 handling operations. Shift performance of the truck (if the working day is 8.5 hours) is calculated as follows:

$$Q_O = \frac{T_{shifts} - (t_{breaks} + t_{waitingtime})}{T_A} = \frac{8.5 - (0.5 + 2 * 0.25)}{14.63} * 60 \cong 30\ LCs \tag{5}$$

The overall performance of the handling equipment while taking into account the mutual interference of concurrent handling operations is about 80 loading operations per 8.5 hour shift.

2.2. Reloading Tracks

In the combined transport terminal in Prerov, there are two handling tracks nos. 405a and 407a with useful lengths of 377 and 285 metres. The reloading track is only the track no. 407a because the track no. 405a is under trolley wire. Therefore, it can only be used as a shunting (siding) track.
The layout of the tracks allows access of the driving car to the unit train from both sides. The total usable length of the two tracks is:

$$l_u = l_{405a} + l_{407a} = 347 + 255 = 602\ m \tag{6}$$

The handling track no. 407a can take 13 rail cars with an average length of 19.64 metres which can be loaded with 39 LCs. The handling track no. 405a can take 17 rail cars with the capacity of 51 LCs but these cannot be reloaded.

2.3. Storage and Reloading Areas

Storage areas at the CTT Prerov are currently divided into three parts with a total capacity of about 180 LCs. Along the reloading tracks is an area on which approximately 66 LCs can be stored in three layers. The other two storage areas are situated at the rear of the CTT, each with the capacity of about 60 LCs in three layers.
The total size of paved areas (storage and reloading area, internal road network) is about 4 200 m^2, out of which the storage area is:

$$S_{LC} = N_{LC} * s_{LC} * \frac{1}{\gamma} * t * \beta = 180 * 19.5 * \frac{1}{3} * 1 * 1.4 = 1\ 638\ m^2 \tag{7}$$

The size of the reloading area is established in two ways because it is influenced among others by the type of the handling equipment and, in the CTT, there are two different types of handling equipment.
The gantry crane on tires PD 38 needs two lanes with a width of 2 metres and in places where the crane rotates, it obviously needs an extended area (i.e. about 15 metres) for handling. When calculating the reloading area, we will not calculate with circular area, but for technical reasons, we will calculate with a square area. We will also presume that the length of the CTT is about 250 metres and the crane will rotate only at one end of the reloading area. The total reloading area for PD 38 will be as follows:

$$S_{PD38} = 2 * 2 * 250 + 15^2 = 1\,225\ m^2 \tag{8}$$

The one side of the forklift truck BP 25 needs the handling area of one lane with a width of 4 metres and its turning radius is about 8 metres. The truck can rotate in two ways, namely:

- Turning in a circle with a radius of 8 metres,
- Rotate using the so-called triangle that has at least two sides of a minimum radius of 8 metres.

However, since the fork lift is only used as a "backup" equipment in the CTT (in case of failure of the crane), we will not consider a separate reloading area for BP 25. Therefore, in the case of using the fork lift for reloading the LCs, the lanes for road vehicles can be used for handling.

2.4. Entrance Gate and Internal Road Network

Entrance gate in the CTT is designed for dispatching the road vehicles on the internal road communication with lay-flat road for two articulated vehicles waiting for dispatch, one of which is located directly on the road. (Lamacz, 2010) In the CTT, it is single-circuit system (direct access of road articulated vehicles to the place of reloading) used.
Local conditions permit driving the road vehicles around the reloading tracks only in one lane in both directions. Road articulated vehicles turn at the back of the CTT near the lay by and storage areas. The distance that articulated vehicles must travel in the CTT is about 500 metres. (Lizbetin, 2011) Internal road network in the CTT takes up an area of about 1 360 m^2, of which approximately 640 m^2 serves the forklift truck BP 25 for loading the trains. Assuming that the speed of the articulated vehicle in the area of the CTT is 20 kmph, we can determine the time the articulated vehicle spends in the CTT as follows:

$$T_V = t_D + t_M + t_C = 2 + (2 * 7) + 10 = 26\ min \tag{9}$$

Where; t_D: driving time of the articulated vehicle in the CTT, t_M : time of handling with LCs (unloading and reloading), t_C : time of inspection and commercial operations.
In the 8.5 hour shift, 17 articulated vehicles can theoretically be served. Technologically, however, it is possible to be commercially checking out one articulated vehicle while the other one is being loaded. The third articulated vehicle in the CTT would cause collision points. The total capacity of the internal road network is therefore about 34 articulated vehicles.

2.5. Summary of Current Performance of the CTT Prerov

The performance of the handling equipment for THE 8.5 hour shift is about 80 loading operations. The capacity of the storage area is about 180 LCs. The track system allows to handle a train with 90 LCs. The internal road network capacity is sufficient to handle 68 LCs per shift.
It follows from the above mentioned that the average daily output of the CTT Prerov is about 68 LCs (the road network is a limiting factor). The annual capacity is about 17 000 LCs.

3. Determination of the Practical Performance of the CTT Prerov after Reconstruction

Reconstruction of the CTT includes mainly construction works (extensions of paved areas designed for the handling and storage of the ITU, as well as the movements of road articulated vehicles; shifting of tracks so that handling with the ITU is possible on both tracks). The reconstruction will also include exchanging the handling equipment for more modern, more efficient and more universal ones (plans count on reloading the ITUs other than large containers) (Lamacz, 2010), (Stopka et al., 2014b), (Nedeliakova et al., 2015).

3.1. Reloading Tracks

After the construction work of the track system, the track no. 407a will be extended by 110 metres and the track no. 405a will be adjusted so that ITUs can be loaded and unloaded on this track as well. The total effective length of both tracks will then be:

$$l_u = l_{405a} + l_{407a} = 347 + 365 = 712\, m \tag{10}$$

After reconstruction, a unit train with 19 rail cars with the average length of 19.64 m which can be loaded with about 57 LCs, can be driven onto the loading track no. 407a. It will be possible to reload on this track as well. The capacity of track no. 405a will remain unchanged, i.e. 17 rail cars with 51 LCs. Therefore, after reconstruction of the CTT Prerov, it will be able to handle a full train with normative length according to the AGTC agreement (max. 700 m). The capacity of the reloading tracks will be 108 LCs per train.

3.2. Performance of Handling Equipment

After reconstruction, two reachstackers Hyster RS 46 will operate in the CTT. Their parameters are as follows:

- Speed: 350 metres per min,
- Load: 46 (resp. 36) tonnes,
- Lift height: 14.9 (resp. 13.4) metres,
- Time of loading operation (t1): 2 - 3 min.

To calculate the time of the loading operation with the outermost LC (T_2), it is necessary to know the arrangement of the LCs on the storage area. They will be arranged in blocks, each block consists of three rows of three layers (local circumstances do not permit stacking of more layers). Time T_1 is therefore two minutes and time T_2 is calculated as follows:

$$T_2 = t_d + n_v * T_1 = 0.57 + 6 * 2 = 12.57\, min \tag{11}$$

Average time T_A is then determined as follows:

$$T_A = \frac{T_1 + T_2}{2} = \frac{2 + 12.57}{2} = 7.29\, min \tag{12}$$

The calculations show that the hourly performance of the reachstacker Hyster RS 46 is 8 handling operations. Shift performance of the reachstacker (if the working day is 8.5 hours) is calculated as follows:

$$Q_O = \frac{T_{shifts} - (t_{breaks} + t_{waitingtime})}{T_A} = \frac{8.5 - (0.5 + 2 * 0.25)}{7.29} * 60 \cong 62\, LCs \tag{13}$$

Performance wise the same two reachstackers (the same types) will operate in the CTT which is why it is not possible to divide them as basic and additional. They will work equally, thereby shortening the travel distance of the vehicle by half. Therefore, the overall performance of the handling equipment in the CTT after reconstruction will be about 120 LCs per shift (8.5 hours).

3.3. Storage and Reloading Areas

The size of the reloading area in the CTT after reconstruction should be about 3 600 m^2. To eliminate the collision points of the two handling devices, this area should be divided into at least two blocks in order to allow the entrance of one of the handling equipment between the LCs which will free the area for crossing the other handling equipment (Xu et al. 2015). These gaps can also be used for temporary unloading the LCs which are stacked and need to be reloaded so that we can get to the LC we need (multiple handling) (Lizbetin et al., 2012). The total capacity of the storage areas is as follows:

$$N_{LC} = \frac{S_{LC}}{s_{LC} * \frac{1}{\gamma} * t * \beta} = \frac{3600}{19.5 * \frac{1}{3} * 1 * 1} \cong 553\, LCs \tag{14}$$

After the creation of two blocks (30*3*3 LC), the overall capacity would be extended to 540 LCs.
The reloading area is determined according to the usable length of the first longer track and the minimal necessary width required for safe rotation of the reachstacker:

$$S_{TA} = 400 * 15.6 = 6\ 240\ m^2 \tag{15}$$

The total size of the storage and reloading areas will be 9 840 m^2.

3.4. Entrance Gate and Internal Road Network

The entrance gate to the CTT is designed to dispatch road articulated vehicles on the internal road with a lay-by for six road articulated vehicles waiting for dispatching when one road articulated vehicle is standing on the road and one lane will remain passable at all times. In the CTT, the single-circuit system will be used (direct access of the road articulated vehicles to the place of reloading).
The road articulated vehicles will pass through the CTT in a one-way circuit. The distance the road articulated vehicles must travel in the CTT is about 850 metres. The internal road network in the CTT will cover an area of about 3 000 m^2, of which approximately 1 500 m^2 will go through reloading area. Assuming the speed of the articulated vehicle in the area of the CTT is 20 kmph, we can determine the time the articulated vehicle spends in the CTT as follows:

$$T_V = t_D + t_M + t_C = 2.5 + (2 * 2) + 10 = 16.5\ min \tag{16}$$

As two equivalent handling devices will work in the CTT, it will be possible to reload two road articulated vehicles at the same time and other two articulated vehicles can be commercially dispatched. Within an 8.5 hour shift, it will be theoretically possible to serve about 100 road articulated vehicles.

3.5. Summary of Performance of the CTT Prerov after Reconstruction

Performance of the handling equipment in an 8.5 hour shift is approximately 120 loading operations. The capacity of the storage area is about 540 LCs. The track system allows for handling a train with 108 LCs. The internal road network capacity is sufficient to handle 200 LCs per shift.
It follows from the above that the average daily output of the CTT Prerov after reconstruction will be about 100 processed LCs (loaded vehicles). The annual capacity is about 50 000 LCs (vehicles).

4. Evaluation of the Change in Performance of the CTT Prerov

Table 2 gives a summary of parameters and overall performance of the CTT Prerov before and after reconstruction.

Table 2
Technical parameters in CTT Prerov

	Status	
	Before reconstruction	**After reconstruction**
total paved area	4 223 m^2	11 360 m^2
storage area	1 638 m^2	3 600 m^2
performance handling equipment	80 lo*/ws**	120 lo/ws
total performance CTT	34 operations/ws	100 operations/ws

** lo – loading operations, ** ws – work shift.*
Source: author

After reconstruction, the total paved area of the CTT increased by almost 170% when the storage area increased by almost 120%. The performance of the handling equipment increased by 50%. Before reconstruction, the handling equipment used only 42.5% of their capacity. After reconstruction, the use of their capacity increased to 83%. The total performance of the CTT increased by 194% (to almost three times of the original performance). The largest share in the increase in overall performance of the CTT is credited to the changing the handling equipment for more efficient ones and changing the internal layout of the CTT and the expansion of the internal road network.

5. Conclusions

The analysis shows that the performance of the CTT is influenced equally by the technical infrastructure of the CTT and by its internal technology. Further rationalization of technology of work (especially in the context of cooperation with road transport and relation to ongoing road transport) could further increase its performance. On the other hand, increasing the number of handling devices would not increase the overall performance of the

CTT without changing the internal terminal technology. Rather, it would decrease the performance because three working handling devices could create collision points in the CTT.

Increasing the operational efficiency can be divided into two planning stages. The first stage should focus on optimal hardware of CTT, which implies a handling equipment (type and number), reloading tracks (with a normative length of 750 m and requisite number), sufficient storage and reloading areas and the proper allocation of these elements. The second stage should focus on optimizing the technology activities of CTT. To optimize technological activities, several mathematical optimization methods can be used. Among these methods, the Critical Path Method (CPM) can be included. It defines the critical activities. These activities have the significant impact on service time, and thus, they directly affect the overall performance of combined transport terminals (Klapita, 2012), (Tadić and Zečević, 2012).

References

Fedorko, G.; Stanova, E.; Molnar, V.; Husakova, N.; Kmet, S. 2014. Computer modelling and finite element analysis of spiral triangular strands, *Advances in Engineering Software*, 73: 11-21.

Klapita, V. 2012. Optimization of logistic chains in the intermodal transport, *Logi: scientific journal on transport and logistics*, 3(2): 57-64.

Kliestik, T. 2013. Optimization of Transport Routes Based on Graph Theory as a Part of Intelligent Transport Systems. In *Proceedings of the 17th International Conference on Transport Means, Transport Means*, 308-311.

Krile, S.; Krile, M.; Prusa, P. 2015. Non-linear mini-max problem of multi-stop flight routes, *Transport*, 30(3): 361-371.

Kubasakova, I.; Kampf, R.; Stopka, O. 2014 Logistics information and communication technology, *Communications*, 16(2): 9-13.

Lamacz, J. 2010. Proposal of criteria of performance of combined transport terminals. Diploma thesis, University of Zilina, Zilina, Sloavakia.

Lizbetin, J. 2013. Terminals of intermodal transport in Slovakia. In *Proceedings of 14th International logistics conference Logi 2013*, 290-295.

Lizbetin, J. 2011. System proposals of combined transport terminals. Habilitation thesis. University of Zilina, Zilina, Sloavakia.

Lizbetin, J.; Kampf, R.; Lizbetinova, L. 2012. Requirements of a Transport System User, *Communications*, 14(4): 106-108.

Nedeliakova, E.; Panak, M.; Kudlac, S. 2015. Qualitative approach to increasing the efficiency of intermodal transport, *Logi - Scientific Journal on Transport and Logistics*, 6(2): 90-98.

Rogić, K.; Marinović, P.; Luburić, G. 2000. Intermodality and Intermodal Cargo Transport in the European Union, *Promet - Traffic&Transportation*, 12(2): 81-86.

Siroky, J. 2011. Automatic Transhipment Systems for Container Transport in Terminals, *Perner´s Contacts*, 6(3): 145-154.

Siroky, J.; Cempirek, V.; Cisarova, H., 2010. Intermodal Transportation of ISO Containers and its Implementation to Freight Transport Centers. In *Proceedings of the International Scientific Conference Management 2010*, 502-512.

Stopka, O.; Kampf, R.; Kolar, J.; Kubasakova, I. 2014. Identification of Appropriate Methods for Allocation Tasks of Logistics Objects in a Certain Area, *Nase More*, 61(1-2): 1-6.

Stopka, O.; Kampf, R.; Kolar, J.; Kubasakova, I.; Savage, Ch. 2014. Draft guidelines for the allocation of public logistics centres of international importance, *Communications*, 16(2): 14-19.

Tadić, S.; Zečević, S. 2012. Development of intermodal transport and logistics in Serbia, *International Journal for Traffic and Transport Engineering*, 2(4): 380-390.

Tadić, S.; Zečević, S.; Krstić, M. 2015. City logistics – status and trends, *International Journal for Traffic and Transport Engineering*, 5(3): 319-343.

Xu, S. X.; Cheng, M.; Huang, G. Q. 2015. Efficient intermodal transportation auctions for B2B e-commerce logistics with transaction costs, *Transportation Research Part B: Methodological*, 80: 322-337.

Zając, M.; Świeboda, J., 2015. Analysis of the process of unloading containers at the inland container terminal. In *Proceedings of the European Safety and Reliability Conference Safety and Reliability: Methodology and Applications*, 1237-1241.

SESSION 7: RAIL TRAFFIC AND TRANSPORT RESEARCH

NEW METHODOLOGY FOR ASSESSING TRANSPORT CONNECTIONS DEPENDING ON THE INTEGRATED TRANSPORT NETWORK

Jozef Gašparík[1], Vladimír Ľupták[2], Pavol Meško[3]
[1,2,3] Department of Railway Transport, Faculty of Operation and Economics of Transport and Communications, University of Zilina, Univerzitná 1, 010 26, Žilina, Slovakia

Abstract: The periodic line transport express an integrated periodic timetable, which is also a periodical liner form of surveillance and network interconnection. An important factor is to reduce the interchange times in selected areas, or transport hubs. The aim is to minimise the total transit time of a passenger from point A to point B. The cornerstone of transport services is to provide travel opportunities by creating links and connections. Often, after the introduction of the new timetable and a discussion of whether it is better or worse, each approach is evaluated in a subjective manner. The authors solved some problems of rail passenger quality services. At present, there is no methodology for assessing train timetables from the transportation point of view as a whole. We evaluate specific trains and connections in the stations only, but not the quality of the connection from point A to point B. The aim of this paper is to introduce a new methodology for the assessment of timetables in terms of passenger traffic, with a focus on connectivity and linking. From the passenger's point of view, it is necessary to assess the availability of travelling opportunities between selected points on the rail network. The travel offer from A to B is in principle affected by travel time, number of transfers (changing the transport means), and number of travel opportunities. Connectivity and linking also affect several factors. This is an outcome in setting the draft criteria for connection evaluation. The introduced study is designed, in purview of the set up, as a tool for an objective evaluation of the quality of public transport service - specifically, the aspects of availability and time services in selected geographical areas in reciprocity to the Standard EN 13816.

Keywords: relation, Lill models, integrated transport network, quality.

1. Dependence of integrated transport network

A transport network is a set of hubs and connecting road sections. On the transport network are moving, entering and then outputting physical objects (e.g. passenger trains, wagon load, etc.). A mathematical model of the network may have a final graph of a finite number of vertices, and a mixed graph with oriented or non-oriented edges, graph G = (V, E, c, d) comprising of a set V of vertices (e.g. train stations, stops, tariff points and so on), a set E of edges (e.g. interstationary sections), c(h) a permeable capacity of the edge or edge part, (h) is the length of the edge.
In transport networks, as in other systems, the distinguishing level is important. The timetables for rail passenger services are sufficient just when one station is in the graph, represented by a single vertex (from network sense, this is called a node). But for the management needs of rail passenger services, each station is designed for the boarding and unboarding of passengers (flow change on the edge) that are seen as a particular peak (Černá and Černý, 2014).
An extension of a conventional line, periodic transport is an integrated periodic timetable (IPTT). In this system are except of periodical repeating of the linear form also monitored the network interconnection and minimising of interchanges times in selected points (transport hubs) where are crossing the individual lines operated for a given period. The aim of this network effect is to minimise the total transferring time of the passenger from point A to point B. This is the most difficult form of operation for transport services, because it demands precision planning and has requirements in terms of boundary conditions. The essential requirements are imposed on the size of the edge periodic time between two nodes, where mutual changes are expected. Substituting the time of the edge can be implemented by a combination of measures related to the infrastructure, setting of the corresponding vehicles, and finally, the connections offered (timetable).
The basis of IPTT consists of the periodic timetable of the superior railway network. Optimal transfer options are given, when all trains meet at the same time at a transfer node (usually it is a transfer train station). In this time period, it is necessary to operate the transfer point by additional means of transport. Thus it is possible, with minimum cost, to transport the passengers from all areas to the transfer stations. In an analogous treatment are passenger transported in the opposite direction in a relatively short time. This creates a scheme of connections in the transfer node, the so-called 'transfer spider'.
Any such transfer spider has a timeline that represents the period of time for the transfer in the node. This timeline determines the edge time. The situation depicted in transfer spiders is regularly repeated after every time period.
The connections meet from opposite directions on the line (for trains crossing) because of timetable symmetry at intervals equal to half the time period. Thus, if the transfer node is situated in the time span of an integer multiple of half of the period, the meeting of lines from the opposite direction is just in these nodes.
The time interval between the symmetrical axes of transfer spiders of two adjacent transfer nodes is called edge time. For periods of one hour, the edge times are 30, 60, 90 minutes. In the systematised transport network described above, one point to any other point can be done without any major time loss from waiting for connections. This possibility should be given for round-trips back to the starting point, so that the axis of symmetry ends in the transfer spider. Therefore, the time required for the round-trip is equal to an integral multiple of the period. These laws shows that the

[2] Corresponding author: vladimir.luptak@fpedas.uniza.sk

timetable conditions of this kind require contingent journey times between nodes, there is no need to prefer the maximum line speed, because all depends on a system travel time.
Using this systemised periodic timetable, rail transport becomes the integrative core of an integrated systematic timetable. By applying the above, the quality of the connection to the transport network is increased, not only at the level of rail transport, but also at the level of integrated transport systems (Drdla, 2014).

2. Continuity of traffic flow between the peaks of the transport network

With the continuity of the traffic flow, it is necessary to choose two places with the coordinates x_1 and x_2 on the route of the transport flow. The size of the flowing masses (e.g. number of trains), located at time t, respectively, $t + \Delta t$, between these points is:

$$\int_{x_1}^{x_2} h(x,t)dx\,, resp. \int_{x_1}^{x_2} h(x,t+\Delta t)dx \tag{1}$$

and thus, their difference, indicating a change of this size is:

$$D = \int_{x_1}^{x_2} (h(x,t+\ \Delta t) - h(x,t)dx \tag{2}$$

This difference of D can be expressed in other ways, such as the difference between during the interval ($t,\ t + \Delta t$) flowing through point x_1 and x_2, and flowing off through point x_2:

$$D = \int_{t}^{t+\Delta t} q(x_1,\tau)d\tau - \int_{t}^{t+\Delta t} q(x_2,\tau)d\tau = \int_{t}^{t+\Delta t} [q(x_1,\tau)d\tau - q(x_2,\tau)]d\tau \tag{3}$$

From the merit of definite integrals results that at each fixed τ, respectively, x is equally:

$$q(x_1,\tau) - q(x_2,\tau) = -\int_{x_1}^{x_2} \left[\frac{\partial q(x_1,\tau)}{\partial x}\right] dx, \qquad h(x,t+\Delta t) - h(x,t) = \int_{t}^{t+\Delta t} \left(\frac{\partial h(x,\tau)}{d\tau}\right) d\tau \tag{4}$$

and thus the difference D can be expressed by a double integral, changing the order of integration:

$$D = \int_{x_1}^{x_2} \left[\int_{t}^{t+\Delta t} \left(\frac{\partial h(x,\tau)}{d\tau}\right) d\tau\right] dx = \int_{t}^{t+\Delta t} \left[-\int_{x_1}^{x_2} \left(\frac{\partial q(x,t)}{\partial x}\right) dx\right] d\tau = \int_{x_1}^{x_2} \left[\int_{t}^{t+\Delta t} \left(-\frac{\partial q(x,\tau)}{dx}\right) d\tau\right] dx \tag{5}$$

Because the first and third integrals have the same limits, and those limits were chosen arbitrarily, also from the integrals equality results integrated functions, and therefore, at any point x and any time τ must be true:

$$\frac{\partial h(x,\tau)}{d\tau} = -\frac{\partial q(x,\tau)}{dx} \Leftrightarrow \frac{\partial h(x,\tau)}{d\tau} + \frac{\partial q(x,\tau)}{dx} = 0 \tag{6}$$

This is one of the most important relationships in traffic flow theory. We call it the continuity equation of traffic flow. In accordance with the physical analogy as well transport flow conditions for the rail transportation conditions, the basic state quantities are characterised, which are necessary for the quality evaluation of connections in the transport network. Generally, there is a need to interpret them for the indicators of relevant quality values. Generally, the state quantities are:

- speed
- intensity = number of units of flow, passing a given point per unit of time
- density = number of flow units per unit distance routes in a given place and a given time
- wave speed = speed of point movement with a given density (Černá and Černý, 2014)

3. Defining quality indicators for the links evaluation on the transport network

The proposed methodology aims to comprehensively cover the possibility of achieving any pair of tariff points by passenger trains on a selected rail network in order to assess the quality of the travel opportunities in the area using selected indicators.

The methodology is based on the evaluation of defined criteria for connectivity between the selected tariff points on the network. Based on the methodology, we evaluate a particular connection. It is necessary to determine whether the connection is evaluated during the workday or the weekend. It is also possible to evaluate a selected workday, Saturday, or Sunday. Consequently, we evaluate the summarising indicators for services in terms of particular relations within the examined networks (Poliak, Križanová, Semanová, and Gajanová, 2014).

For assessing the connectivity and quality of connections in an examined relation (session), we identify the following factors, some of which are introduced in literature (Majerčák et al. 2015):

- Number of connections N_s during the reporting day, direct connections as well connections with changes (transfers).
- Average waiting time of passenger W_i. This is the time that the passenger has to wait for a connection to a point of departure, or possibly a transfer point. It is defined as half of the time between the departure of two successive connections.
- Distance route of relation L_i. This is the travel distance by vehicles creating the connection. This criterion is important to calculate transportation speed and the rate of achievement.
- Type and number of trains creating the connection. This factor reflects the quality of transport services on the connection.
- Transportation time T_p. Time between the departure from the boarding station on the route and disembarking the train at the destination railway station (tariff point).
- Number of transfers (changing means of transport) N_p. This is the absolute number of changes of transport vehicles (trains) before reaching the target station.
- Transfer time T_w. This is the total time that passengers spend waiting for connections at the transfer station (by changing means of transport) when using a particular connection.
- Achieving time T_D. This is the time from embarking when the travel trip begins, to the arrival of the train at the destination railway station. It is calculated as the sum of the average waiting time and transportation time.
- Transportation speed V_P. This is given as a proportion of the distance travelled and time of transfer.
- Achieving start-stop speed V_D. This is given as a proportion of the length of the relation and achieving time.

Transportation speed and achieving speed are important evaluation criteria for the quality of a particular connection relation. They are convenient indicators for comparing public transport link connections with individual transport (Gašparík, Široký, Pečený, and Halás, 2014).

After processing the connections, an evaluation of a single session is necessary to evaluate the relation between tariff points on the network. For each session averages of criteria for all connections are calculated: the number of tranfers, transfer time, the speed of transfer rate and speed of achievement (Zitrický, Gašparík, and Pečený, 2015).

Table 1

Sample of connection assessment on the X – Y relation (workday)

Connection Number	Station X departure [hh:min]	Station Y arrival [hh:min]	Average waiting time W_i [h]	Connection distance L_i [km]	Transport means	Transport time T_p [h]	Number of transfers N_p	Total changing time T_w [min]	Start-stop achieving time T_D [h]	Travel speed V_P [km.h^{-1}]	Start-stop achieving speed V_D [km.h^{-1}]
1	6:53	9:36	6.25	158	R,	2.72	0	0.00	8.97	58.16	17.62
2	8:03	12:20	0.58	192	R,Os,Os	4.28	2	0.28	4.87	44.82	39.45
3	10:53	13:44	1.42	158	R	2.85	0	0.00	4.27	55.44	37.03
n	18:53	21:35	1.42	158	R	2.70	0	0.00	4.12	58.52	38.38
Average per connection:							0.88	0.22	4.96	53.04	38.49

Source: Authors

3. An adequate number of network connection using the Lill model

In transport planning, it is possible to encounter situations where it is necessary to determine quantified estimates of the size of traffic flows between two points over a selected period of time (intensity, density), for situations where it is not possible to carry out a direct survey of transport demand. It is also necessary, in some cases, to determine the impact of individual measures of the transport department of the size of its traffic share. This applies particularly to the number of changes in transport, the number of connections or transport distances.
For these reasons, empirical models are used for determining of the passenger flow characteristics (Lill's model), which is closely related to the number of available network connection.

3.1. Lill's model

Lill's model is used to determine the approximate number of connections between two settlement units, where the distance is generally considered between centres. Lill's model has the following form (Drdla, 2014):

$$j_{1,2} = \frac{A_1 \cdot A_2}{d^n} \cdot K \tag{7}$$

where:
$j_{1,2}$ number of trips between the two cities for a specified time period
$A_{1,2}$ population (in thousands) at specific locations
d distance places
K index (is depending on the largeness and binding of locations 1 and 2),
N value approaching the value of 2.

3.2. The calculation of the optimal number of connections for the selected sessions

In practice, however, using the gravity model is usually not easy and cannot be applied entirely to all relations. This is also evident from the complex determination of the index K, which usually has a value of about 150, but in the case of two cities with a high population density and a short distance between them, this index can be significantly reduced (Stopka, Šimková, and Konečný, 2015).
For the application of the model, selecting the appropriate conurbation is needed, which will be analysed in detail in a case study using Lill's gravity model. We introduce an example calculation for the conurbation Leopoldov–Trnava (in Slovakia):

$$j_{1,2} = \frac{A_1 \cdot A_2}{d^n} \cdot K = \frac{4{,}143 \cdot 64{,}439}{17^2} \cdot 150 = 138.5\ link/24\ hours \tag{8}$$

The calculated values represent the optimal number of total connections of public passenger transport in both directions (Ľupták, Gáborová, and Zitrický, 2015).

4. Conclusion

The proposed methodology is used for the possibility of achieving any pair of tariff points in a selected railway network comprehensively. It not only offers an evaluation of the connectivity of a particular relation, but also objectively assesses the availability of connections between two selected tariff points, based on quality indicators such as average number of transfers, average waiting time, average transportation speed, and average achieving speed. This enables us to evaluate the quality of the travel opportunities in this area by using selected indicators. Subsequently, using Multiple criteria analysis allows us to evaluate the degree of customer satisfaction with selected quality attributes based on their importance. Ultimately, it is possible to examine the statistical dependence of the number of transported rail passengers by examining the quality connection of the network.
The proposal will contribute to the creation of a competitive transport system that efficiently uses system resources. Such is the plan of a Single European Transport Area within the purview of the white paper, 'Roadmap to a Single European Transport Area—Towards a competitive and resource efficient transport system'. This aims for the attainment of an efficient and integrated system of mobility. The importance of the quality, accessibility, and reliability of transport services in the coming years may be even more important.
Another aim of the article is to outline the methodology for determining the required number of transport links between settlement units in passenger traffic. In terms of passengers, it must assess the availability of opportunities to travel between selected points on the transport network. Offering transportation from point A to point B in principle affects transportation time, the number of connections and the number of travel opportunities. On connections and the transfer, connections are thus influenced by a number of factors in transport planning, which is the basis for the empirical model.

Acknowledgements

The paper is supported by the VEGA Agency under Project 1/0095/16, 'Assessment of the quality of connections on the transport network as a tool to enhance the competitiveness of public passenger transport system'.

References

Černá, A.; Černý, J. 2014. *Managerial decisions about transport systems* (in Czech), University of Pardubice 2014, 230 p, ISBN 978-80-7395-849-7.

Drdla, P. 2014. *Passenger traffic regional and national importance* (in Czech), University of Pardubice, iss. 1., 2014, 412 p., ISBN 978-80-7395-787-2

Gašparík, J.; Široký, J.; Pečený, L.; Halás, M. 2014. Methodology for assesing the quality of rail connections on the network, *Communications: scientific letters of the University of Žilina*, 16(2): 25-30. ISSN 1335-4205.

Ľupták, V.; Gáborová, V.; Zitrický, V. 2015. The application of empirical models in transport planning in the Slovak Republic, *Zeleznicna doprava a logistika*. ISSN 1336-7943, 10-13. Available from Internet: <https://fpedas.utc.sk/zdal/images/zdal/archiv/zdal_2015_02.pdf> (in Slovak).

Majerčák, et al. 2015. *Transport and communication systems*. Dolis Bratislava, iss. 1., 262 p.

Poliak, M.; Križanová, A.; Semanová, Š.; Gajanová, Ľ. 2014. The influence of contract form choice of the transport services ensuring on performance contracting entity requirement, *Transport Problems = Problemy Transportu: international scientific journal*, 9(4): 153-161, ISSN 1896-0596.

Stopka, O.; Šimková, I.; Konečný, V. 2015. The quality of service in the public transport and shipping industry, *Nase More, Dubrovnik: University of Dubrovnik*, 62: 126-130, Special Issue, ISSN 0469-6255.

Zitrický, V.; Gašparík, J.; Pečený, L. 2015. The methodology of rating quality standards in the regional passenger transport, *Transport Problems = Problemy Transportu: international scientific journal*, 10: 59-72.

ASSESSMENT OF THE SUSTAINABILITY OF TRADITIONAL AND INNOVATIVE RAIL TRACK SYSTEMS IN A LONG-TERM PERSPECTIVE

Marinella Giunta[1]
[1] DICEAM – University Mediterranea of Reggio Calabria, Reggio Calabria, Italy

Abstract: In the last decades special attention is being paid to ballast-less track systems, for their more suitability to be applied in high-speed lines with respect to the ballasted systems. Considering this fact, the present study aims at evaluating the technical, economic and environmental features of competing track solutions in a long-term perspective in order to ascertain their sustainability. Traditional track, who main components are: ballast, sleepers, fastenings, baseplates, rails; and innovative track, usually constituted by pre-stressed concrete slab, fastenings, pad and rails, are put in comparison. Regarding the technical aspects, the advantages and disadvantages of each solution are analyzed, considering the traffic and the speed of the railway line. For the economic aspects, the costs of construction, maintenance and renewal are considered. The environmental aspects account for the impacts produced by the construction/maintenance/renewal activities, and they are estimated in terms of greenhouse emissions (CO_2e) and related cost. A LCCA-based method for assessing the best strategy for the design and management of a railway track over time (maintenance and renewal), considering a long-term perspective, is also set up. Results shows that solutions reasonably priced in the short period could become less sustainable in a long period.

Keywords: ballasted track, slab track, sustainability, LCCA.

1. Introduction

Emerging issues in railway track design and maintenance are related to the worldwide trend towards the increase of axle loads and train speed. Loads and speed induce on the tracks a wide range of bearing and bending stresses in the rails, fasteners, sleepers/slabs, ballast and subgrade due to: i) the static mass of the vehicles; ii) the dynamic actions, such as lateral centrifugal forces on curves, longitudinal acceleration and braking forces; iii) vertical inertial forces from the motion of the wheel-set and its suspension; iv) the vibrational forces induced from imperfections in the rail surface (corrugations, joints, welds, defects) and in the wheels (flats and shells); v) the dynamic response of the track components to the above actions (Tzanakakis, 2013). The need to make the track suitable to withstand these stresses requires an accurate design and includes enhanced maintenance concepts and new or improved construction methods (Esveld, 1999; Esveld, 2001; Gautier, 2015). To this purpose, in recent years special attention is being paid to ballast-less track systems for their more suitability, with respect to the ballasted systems, to be applied in high-speed lines or in lines in which the passenger trains share the track with the freight trains. Ballast-less track slab is a continuous slab of concrete in which the rails are usually supported directly on the upper surface by using resilient pad.

Low maintenance costs (approximately 20-30% less), higher availability, increased service life (50 – 60 years), higher lateral stability, reduction of weight and height of the track, and easier and more economic vegetation control are the main strength points of slab track with respect to the ballasted track, while the weaknesses are: higher construction cost and higher noise radiation due to the lack of noise absorption of the ballast bed (Bilow& Randich, 2000; Esveld, 2001; Darr & Fiebig, 2006; Lichtberger, 2005). Concrete slab track and rail pads dampen some noise frequencies but may reflect other frequencies and this should be addressed in the design and maintenance of slab track (Di Mino, et al. 2009). The mitigation of noise and vibration further increases the costs of the slab track construction significantly.

In the light of the advantages and disadvantages of the competing track solutions the choice of the more effective system, considering the level of traffic in the line, the maximum speed allowed and other boundary conditions, can be supported by an accurate and comprehensive Life Cycle Cost (LCC) analysis, because of the long-lasting impacts related to design choices. According to ISO 15686-5, LCC can be defined as “the cost of an asset or its parte throughout its life cycle, while fulfilling the performance requirements”.

Since the early stage of inception of track design, it is important to take into account the various phases of the life cycle (construction, operation, maintenance, and disposal). In fact, it is very difficult to modify the initial track design, while, on the other side, the performance of the infrastructure depends largely on maintenance and renewal strategies. The track design phase needs to carefully consider all costs during the life span, such as agency costs, user costs, externality costs together with the required performances such as Reliability, Availability, Maintainability, and Safety (RAMS) at system and component level. In this way it is possible to properly evaluate the sustainability of different solutions and recognize the most convenient. After construction and installation, LCCA and RAMS assessment can provide a useful aid for making effective maintenance and operational decisions.

In the present paper a LCCA-based model able to evaluate the total cost of competing track solutions is proposed. By means this model, the traditional track, who main components are ballast, sleepers, fastenings, baseplates, rails; and the innovative track, usually constituted by pre-stressed concrete slab, fastenings, pad and rails, are put in comparison. The technical features of each solution, considering the traffic and the speed of the railway line, the economic aspects, such as the costs of construction, maintenance and renewal and the environmental impacts produced by the construction/maintenance/renewal activities, estimated in terms of greenhouse emissions (CO_2e) and related cost are considered in the assessment.

[1] Corresponding author: marinella.giunta@unirc.it

The model aims at evaluating the best strategy for the design and management of a railway track over the time (maintenance and renewal), considering a long-term perspective and tangible and intangible costs.

2. Methodology for LCC analysis

The railways, as any other transport infrastructures, require relevant resources to guarantee their efficiency and functionality along the time. In Europe, the construction cost of track ranges from 0.4 to 0.6 million of euros/km for single track, while the maintenance costs can vary from 30.000 to 100.000 €/km per year [Baumgartner, 2001; Jimenez-Redondo et al. 2012]. The railway owners generally support these costs. Other important costs, not directly sustained by the owners but affecting the community, relate with the environmental impacts connected to construction, operation and maintenance/renewal of the track. Few data are available regarding the environmental costs even if the environmental concerns have an increasing importance in design and maintenance decision-making process [Milford and Allwood, 2010; Lee, 2008]. All the mentioned costs should be taken into account in decision-making process (new construction projects or maintenance strategies for existing assets) in order to address the properly choices.
In this context, the Life-Cycle Cost Analysis (LCCA) is an effective technique. In fact, LCCA is an engineering economic analysis tool that enables to quantify the differential costs of alternative investment options for a given project. LCC provides the theoretical concepts needed to balance short-term and long-term costs and performances and allows the economic assessment of competing design alternatives considering all significant costs (Zoeteman, 2001; Stalder, 2001; Esveld, 2001).
A comprehensive life cycle cost analysis requires the consideration of all the costs supported during the track life span (Praticò and Giunta, 2016). These costs can be encompassed in three main categories (see Fig. 1):

- Agency costs due to the construction, maintenance and renewal activities,
- User costs mainly related to the delays produced in the railway service by the maintenance and renewal activities,
- Externality costs associated to the impacts on the environment in terms of climate change (co2e), air quality (sox, nox, co, voc, pm, etc.), noise, water quality, soil quality, biodiversity, land take, quarries, landfills, and visual effects (yin and siriphong, 2006; ian et al., 2009) produced by activities and processes carried out during construction/maintenance/renewal, (i.e. Transportation, quarrying, landfill use, cement/steel/rubber production).

In order to implement the LCCA, two main phases have to consider:

- the Life Cycle Inventory (LCI), which is the data collection portion of LCCA. LCI is the straightforward accounting of everything involved in the "system" of interest. It consists of detailed tracking of all the flows in and out of the system, including raw resources or materials, construction processes, energy, emissions to air (CO2e), unit costs. This kind of analysis can be extremely complex. A correct approach to this phase requires a definition of the scope of the LCC analysis having into account that if the scope is too large the tool may become impractical to use and of limited ability to help in decision-making and consideration of alternatives; if the scope is too small then the results may be skewed by the choice of factors considered such that the output becomes unreliable or partisan,
- the Life Cycle Cost Model (LCCM), which defines all costs quantitatively and by means the appropriate discounting allows determining the total cost pertaining to a given solution.

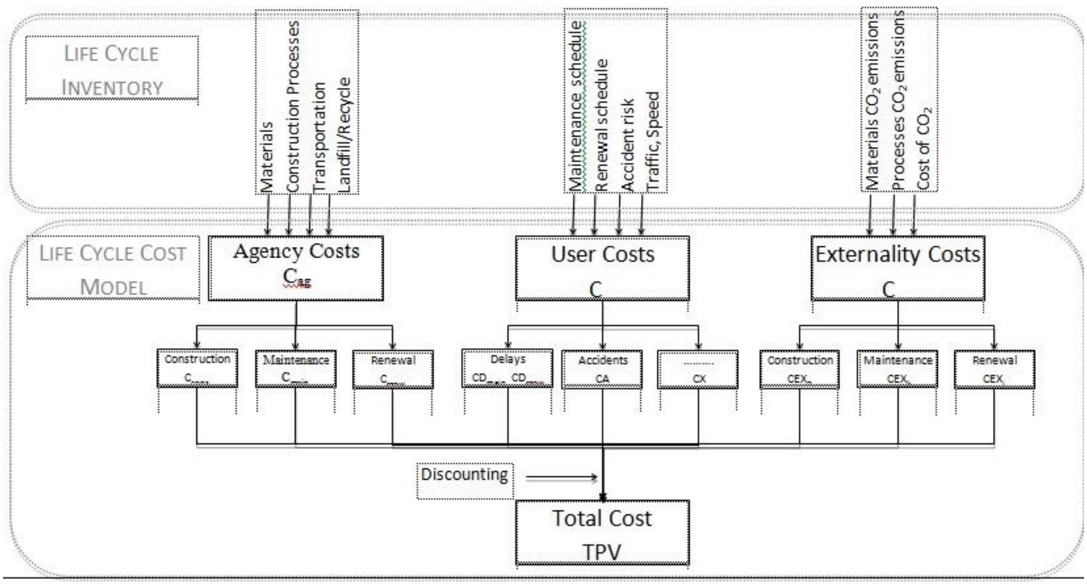


Fig. 1.
Life Cycle Inventory and Life Cycle Cost Modelling

Considering the above discussion, to each track alternative can be associated the total cost (C_{tot}) defined as per equation (1):

$$C_{tot} = C_{ag} + C_{us} + C_{ex} \tag{1}$$

Where; C_{ag} :are the agency costs, C_{us}: the user costs, C_{ex} : the externality costs.
The agency costs refer to the cost of track construction (C_{cons}) and to the costs for maintenance (C_{main}) and renewal (C_{renw}). The agency costs can be split as follows:

$$C_{ag} = C_{cons} + C_{main} + C_{renw} \tag{2}$$

Costs of construction mainly depend on the expense for materials (supply, transportation, etc.) and construction processes; they can be easily estimated based on executed or on going railway projects.
Maintenance encompasses all the minor activities aiming at repairing (corrective maintenance) or preventing (preventive maintenance) rails and sleepers damage, tamping, track stabilization, ballast injection, etc.. Maintenance costs are affected by the traffic (typically the Millions of Gross Tons) and speed: the higher the traffic the higher the maintenance costs and higher speeds correspond to higher maintenance costs (Baumgartner, 2001; Silavong et al., 2014; Thompson, 1986).
Obviously the maintenance strategy adopted by the owner and established since the design stage affect the schedule of the activities (type and time for the interventions) and the related costs.
To the aims of the life cycle cost analysis, the costs for ordinary and extraordinary maintenance can be considered as costs running annually (Baumgartner, 2001). Based on this assumption the annual maintenance costs in this proposed method for LCCA can be estimated by means of the following formulas, set up and calibrated based on the data gathered from Italian projects and international literature (Praticò and Giunta, 2016; Praticò and Giunta 2016a):

$$C_{main} = \left[2.2 \cdot \frac{(V-100)}{200} + 4\right] \cdot GTK^{\left[-0.05 \cdot \frac{(V-100)}{200} + 0.63\right]} \tag{3}$$

Where; C_{main} : refers to the annual maintenance costs (k€, thousands of euros, per single track, per kilometer) V in Km/h is the maximum speed allowed in the line and GTK is traffic expressed by means the indicators gross ton kilometers [ton*km].
Renewal concerns the substitution of the main components of track (ballast, rails, sleepers, slabs, etc…). This activity is linked to the service life of the components and the related costs comprise also the expenditure for disposal and reconstruction.
The user costs are mainly related to the delays originated by restrictions (reduced speed, inoperativeness of railway components, etc.) due to the work zones.
According to Lovett et al., 2015, delays can be divided into two general categories: routine (experienced during normal operations, including crew changes, meets, passes, and civil speed restrictions) and irregular (including maintenance, accidents, and short-term speed restrictions based on track conditions). In the present study, based on owner's standpoint, the irregular delays due to maintenance and renewal of track have been considered and calculated as (Lovett et al., 2015):

$$CD = ((CO + CF)xNL + CW)xTD \tag{4}$$

Where; CD: cost of delay (euro/train-hour), CO: the locomotive operating cost (euro/locomotive-hour), CF: the fuel cost (euro/locomotive-hour), NL: the average number of locomotives, CW: the crew cost (euro/train-hour), TD: the length of delay (hours).
The user costs for delays due to maintenance and renewal are

$$\begin{aligned} C_{us} &= CD_{main} + CD_{renw} = ((CO + CF)xNL + CW)xTD_{main} \\ &+ ((CO + CF)xNL + CW)xTD_{renw} \end{aligned} \tag{5}$$

Where; CD_{main} and CD_{renw} : the costs for delays caused by maintenance and renewal activities respectively, TD_{main} : the average length of delays for maintenance activity, TD_{renw} : the average length of delays for renewal activity.
The externality costs refer to the sum of all costs of environmental impacts produced during the construction and the life cycle of the track (CEX_{kj}). To each j-th impact produced by the k-th process (Q_{kj}), can be associated a unit cost (UP_{kj}). Having in mind the symbols already defined the externality costs can be calculated by means of this equation:

$$C_{ext} = \sum_k \sum_j CEX_{kj} = \sum_k \sum_j Q_{kj} \cdot UP_{kj} \tag{6}$$

The quantification of these costs is a difficult task; in this work the quantity of CO_2 equivalent corresponding to the given process and material has been considered.
As it is well known, carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years).
Regarding the cost of a ton of CO_2, it should be noted that it is extremely variable and this variability is a critical factor because of determines a different incidence of externality costs on total cost.
Consequently, in a long-perspective an equilibrium between the sum of agency and user costs (tangible costs) and externality cost (intangible costs) is needed. To this aim a balancing factor (ν) has been defined as the minimum ratio tangible to intangible costs (see equation 10).
In order to make all the discussed and defined costs comparable, they are discounted to a base year considering the interest (r) and inflation (i) rates. The present values (PV) for the quoted costs can be calculated by means of the equations from (7) to (9):

$$PV_{ag} = C_{cons} + \sum C_{main} \cdot \left(\frac{1+i}{1+r}\right)^{Emain} + \sum C_{renw} \cdot \left(\frac{1+i}{1+r}\right)^{Erenw} \tag{7}$$

$$PV_{us} = \sum CD_{main} \cdot \left(\frac{1+i}{1+r}\right)^{Emain} + \sum CD_{renw} \cdot \left(\frac{1+i}{1+r}\right)^{Erenw} \tag{8}$$

$$PV_{ext} = CEX_0 + \sum_k CEX_k \cdot \left(\frac{1+i}{1+r}\right)^{E_k} \tag{9}$$

Where; PV_{ag} : the present value agency costs, PV_{us} : the present value user costs, PV_{ext} : the present value externality costs, i :the inflation rate, r : the interest rate, CEX_0 and CEX_k refer to the externality costs at construction stage and at k-th maintenance/rehabilitation phase respectively, E_{main}: the expected life for maintenance activity, E_{renw} : the expected life for renewal, E_k is the expected life for the k-th activity of maintenance or renewal.
The total present value (TPV) of a given alternative is the sum of the present values of all costs related to them, as already defined. In order to take into account the issue related to the CO_2 cost fluctuation, which affect the externality cost, a balancing factor has been defined as follows:

$$\nu = \min_{j=1,2,..k} \frac{PV_{ag_i} + PV_{uc_i}}{PV_{ext_i}} \tag{10}$$

Where j : the j-th alternative, and k: the number of the alternatives in comparison.
Having in mind this factor, the TPV for a given j-th alternative can be derived from the equation:

$$TPV_j = PV_{ag_j} + PV_{uc_j} + \nu \cdot PV_{extj} \tag{11}$$

3. Application and results

The proposed method for Life Cycle Cost Analysis has been applied to two competing track alternatives: the traditional ballasted track and the ballast-less track. Various types of innovative ballast-less track systems are in service around the world.
The most popular are the Bögl, Shinkansen, Rheda, Sonneville-LVT, Züblin, Stedef and Infundo-Edilon [Esveld, 2001], here the Shinkansen system is considered (Fig. 2). For both the alternatives a double track line 1-km long has been accounted in the application.
Table 1 shows the main characteristics of the components for the two considered track alternatives. For each component an average service life has been also assumed [Milford, et al. 2010].

Table 1
Track components: main characteristics and expected service life

Component	Service life [Years]
Rail *60 UNI, mass= 60,1 Kg/ml*	28
Sleepers *Pre-stressed mono-block, L= 2.60 m, mass= 325 Kg equipped with baseplate*	40
Fastenings *Elastic type Vossloh W14 AV*	40
Ballast *Crushed stones, 500 mm (aver. depth)*	40
Subballast/Concrete road-bed *Cement treated layer 200 mm depth*	40
Slab *Pre-stressed concrete with cylindrical bollard* *4,93 m x 2,34 m x 0,19 m; mass = 5 tons*	60

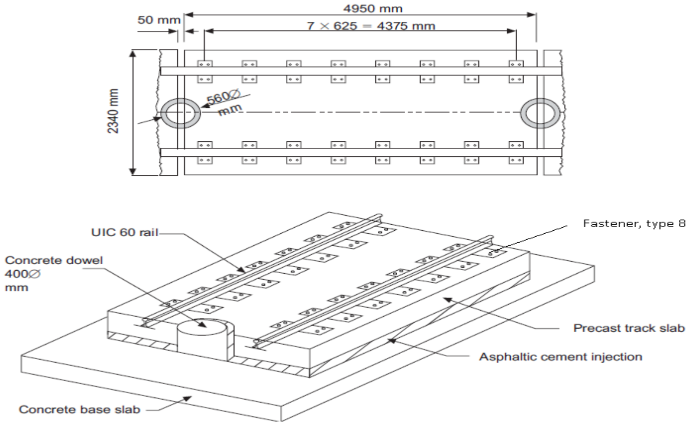


Fig. 2.
Slab track
Source: Esveld 2001

Results of the application are shown in figures 3-5.
Figure 3 represents the trend of TPV for the two alternatives, the ballasted (blue continuous line) and the slab track (red dashed line). As it can be observed, at end of construction (year 0), the total cost of slab track is higher of about 1.5 times than the one of the ballasted track, this finding complies with the existing international literature [Schilder and Diederich, 2007; Pichler and Fenske, 2013; Gautier, 2015]. Note that in this case the total cost encompasses both construction and externality costs. After about 26 years a breakeven of the total present values of the two solutions can be observed. In the successive years the total present value of slab track remains lower with respect to the one of ballasted. The difference between the two costs is quite small.

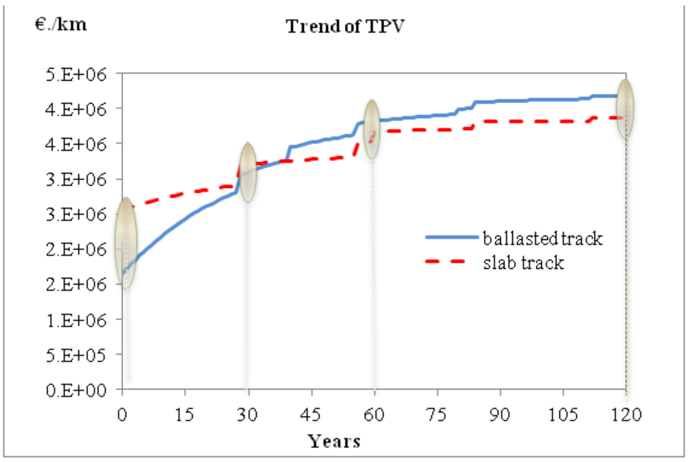


Fig. 3.
Trend of TPV for ballasted and slab track

In order to understand better the sustainability of the two solutions under the different standpoints, costs of construction and management, user costs and environmental costs, the following figures 4 and 5 provide a breakdown of these costs in different time frame of track life: 0, 30, 60, and 120 years.

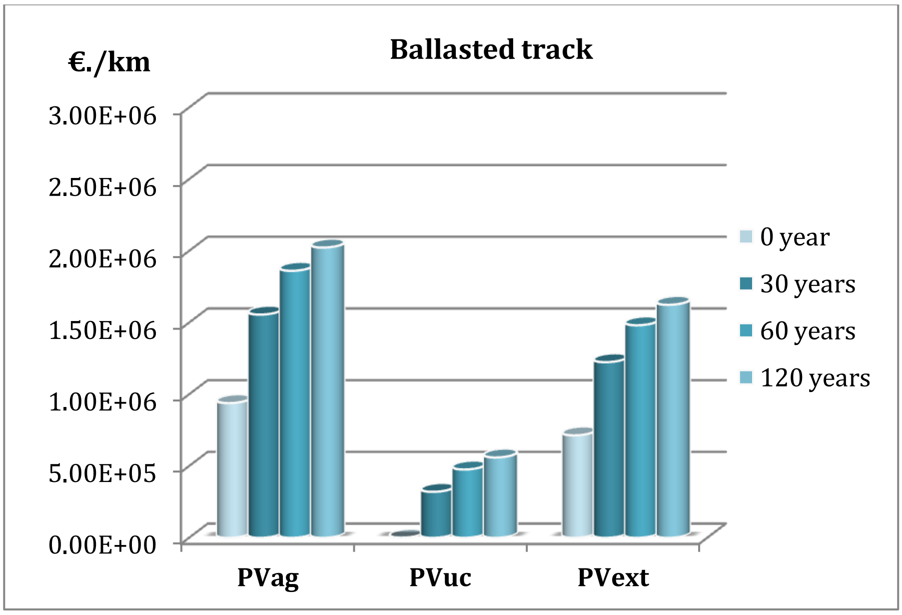


Fig. 4.
Trend of agency, user and externality costs for ballasted track in the time frame 0, 30, 60 120 years

With regard to the agency costs, despite the lower construction cost of the traditional ballasted track (if compared to the slab track), the more maintenance exigencies during the life cycle make this solution quite expensive in the long term. For this aspect, the slab solution exhibits an opposite trend namely higher construction cost and lower maintenance and renewal costs.

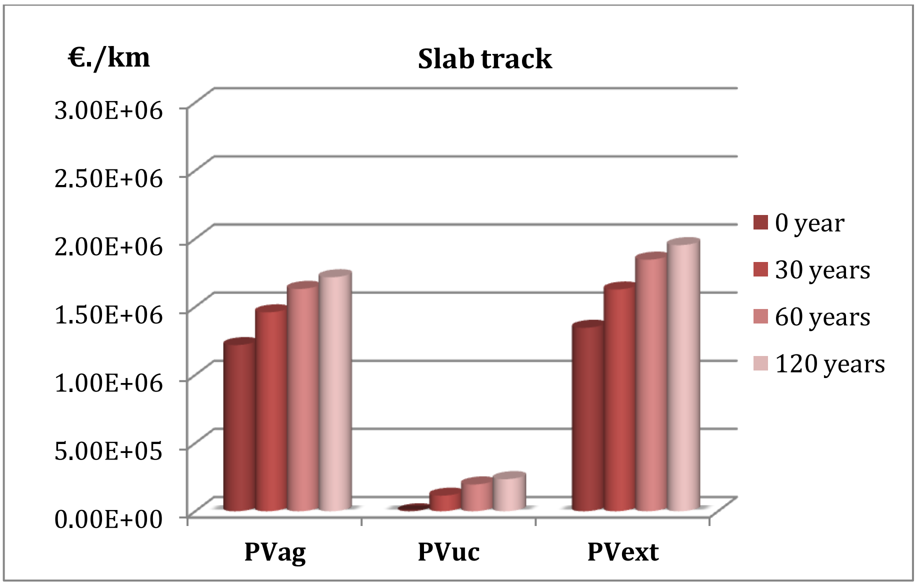


Fig. 5.
Trend of agency, user and externality costs for slab track in the time frame 0, 30, 60 120 years

The user costs, follow the same trend of the agency costs; their value is, in fact, affected by the maintenance and renewal activities connected to the two solutions, because of the delays produced for passengers and freight moving in the railway line. For this reason, the lower maintenance exigencies and the higher service life of the slab track make this solution more favourable than the ballasted track.
From the environmental standpoint, the slab track appears less preferable than the traditional ballasted track. This is mainly due to the carbon footprint associated whit the cement and concrete production. The embedded carbon factor of

a slab track is 0.3-0.4 Kg CO_2/Kg while for ballast and the sleepers is respectively 0.005 Kg CO_2/Kg and 0.27-0.28 Kg CO_2/Kg (Milford, 2010, Praticò et. al 2013).

3. Discussion and conclusion

Results of the LCCA analysis carried out on the two track systems ballasted and ballast-less, following the method set up, confirms that a comprehensive evaluation of different track options needs the consideration of agency, user and externality costs. In fact, tangible and intangible costs govern the suitability of a track to fit transportation and environmental demand. Considering and integrating technical issues and environmental concerns may be a difficult task, but it results the best way to make a complete comparison among different design and maintenance track solutions. Based on the findings of this study the following conclusions can be drawn.

As obvious, the total cost for the two track solutions, increases over time while the growth rate decreases. The two solutions even if at construction stage exhibit a significant different value (higher for slab track), after less than 30 years reach a breakeven and invert the trend. Based on the total cost, the evaluation of the two solutions is different depending on whether it refers to the short or long term.

The break-down of the costs allows highlighting some significant conclusions.

The agency costs (construction, maintenance and renewal), lower at construction stage and in the short period for the ballasted track with respect to the slab track, in a long term perspective, for the first solution yield a value which is 1.15 times higher than the one of the slab track.

The user costs for ballasted track, lower in the short period, become, in the long term perspective, 2.3 times higher than the ones exhibited by the slab track.

The environmental costs show an opposite tendency for the two solutions. In more detail, the carbon footprint is a key factor in the comparison. The CO_2 emission for cement/concrete is very high if compared with the ballast. Consequently for the slab solution the externality costs are 1.2 times higher than the traditional track.

In the light of the above consideration, in a long-term and general perspective, the ballast-less track solution results preferable with respect to the traditional ballasted track.

The above results can benefit both researchers and practitioners.

References

Baumgartner, J.P. 2001. *Prices and costs in the railway sector*. École Polytechnique fédérale de Lausanne. Laboratoire d'Intermodalité de Transports et de Planification.

Bilow, D.N.; Randich, P.E.,2000. *Slab track for the next 100 years*. Portland Cement Association. Skokie, Portland U.S.A.

Lichtberger B. *Track compendium*, *First edition*, Eurail Press, Hamburg, Germany.

Darr, E.; Fiebig, W. 2006. *Feste Fahrbahn: Konstrktion und Bauarten für Eisenbahn und Strassenbahn*, *Second edition*, Eurailpress, Germany.

Di Mino, G.; Giunta, M.; Di Liberto, M.C. 2009. Assessing the open trenches in screening railway ground-borne vibrations by means of artificial neural network, *International Journal Advances on Acoustics and Vibration*, 1687-6261.

Esveld, C. 1999. Slab track: A Competitive Solution. Available from Internet: <http://www.esveld.com>.

Esveld, C. 2001. Modern Railway Track, Second Edition. Available from Internet: <http://www.esveld.com>.

Gautier, P.E. 2015. Slab track: Review of existing systems and optimization potentials including very high speed, *Construction and Building Materials*, 92: 9-15.

Ian, W.H.; Parry, I.W.H.; Timilsina, G. R., 2009. Pricing Externalities from Passenger Transportation in Mexico City, Policy Research Working Paper 5071, The World Bank, Development Research Group. Environment and Energy Team, Washington, D.C., U.S.A.

Jimenez-Redondo, J.N.; Bosso, N.; Zeni, L.; Minardo, A.; Schubert, F.; Heinicke, F.; Simroth, A. 2012. Automated and cost effective maintenance for railway (acem-rail), *Transport Research Arena*, 48:1058-1067.

Lee, C.K.; Lee, J.Y.; Kim, Y.K.; 2008. Comparison of environmental loads with rail track systems using simplified life cycle assessment (LCA), *WIT Transactions on the Built Environment*, 101:367-372.

Lichtberger, B. 2005. *Track compendium*. *First edition*, Eurail Press, Hamburg, Germany.

Lovett, A.H.; Dick, C.T.; Ruppert, C.J.Jr.; Barkan, C.P.L. 2015. Cost and delay of railroad timber and concrete crosstie maintenance and replacement, *Transportation Research Record: Journal of the Transportation Research Board*, 2476: 37-44.

Milford, R.L.; Allwood, J.M, 2010. Assessing the CO2 impact of current and future rail track in the UK, *Transportation Research Part D*, 15: 61-72.

Pichler, D.; Fenske, J. 2013. Ballastless track systems experiences gained in Austria and Germany. In *Proceedings of the AREMA Annual Conference, Indiana Convention Center Indianapolis*.

Praticò, F.G.; Vaiana, R.; Giunta, M.; Iuele, T.; Moro, A., 2013. Recycling PEMs back to TLPAs: Is that possible notwithstanding RAP variability?, *Applied Mechanics and Materials*, 253-255:376-384.

Praticò, F.G.; Giunta, M., 2016. Assessing the sustainability of design and maintenance strategies for rail track by means of life cycle cost analysis. In *Proceedings of the COMPRAIL 2016 15th International Conference on Railway Engineering design and operation*, 162:251-262.

Praticò, F.G.; Giunta, M., 2016a. Issues and perspectives in railway management from a sustainability standpoint. In *Proceedings of International Conference on Transportation Infrastructure and Materials*.

Schilder, R.; Diederich, D., 2007. Installation Quality of Slab Track - A Decisive Factor for Maintenance, *2007 RTR Special*, 76-78.

Silavong, C.; Guiraud, L.; Brunel, J., 2014. Estimating the marginal cost of operation and maintenance for French railway network. In *Proceedings of the ITEA Conference–Toulouse, France*.

Stalder, O. 2001. The life cycle costs (LCC) of entire rail networks: An international comparison, Rail International, *International Railway Congress Association*, 32(4): 26-31.

Thompson, L. S. 1986. High-Speed Rail, *Technology Review*, 89: 32-43.

Lovett, A.H.; Dick C.T.; Ruppert, Jr. C.J.; Barkan C.P.L., 2015. Cost and delay of railroad timber and concrete crosstie maintenance and replacement, *Transportation Research Record: Journal of the Transportation Research Board*, 2476: 37-44.

Tzanakakis K. 2013. *The Railway Track and Its Long Term Behaviour. A Handbook for a Railway Track of High Quality*, Springer Tracts on Transportation and Traffic, 2(2013): 279-292.

Yin Y.; Siriphong L. 2006. Internalizing emission externality on road networks, *Transportation Research Part D: Transport and Environment*, 11(4): 292-301.

Zoeteman, A. 2001. Life cycle cost analysis for managing rail infrastructure: Concept of a decision support system for railway design and maintenance, *EJTIR*, 1(4): 391-413.

SIMULATION OF TRAIN TRAFFIC ON A SINGLE TRACK LINE PASSING SIDINGS USING OPENTRACK

Dušan Jeremić[1], Sanjin Milinković[2], Miloš Ivić[3], Andreas Schöbel[4], Milan Milosavljević[5], Jelena Aksentijević[6]
[1,2,3,5] University of Belgrade, Faculty of transport and traffic engineering, Belgrade, Serbia
[4,6] OpenTrack Railway Technology GmbH, Vienna, Austria

Abstract: Simulation modelling is today widely used and acknowledged as a very efficient and reliable technique for analyzing train movements. During the simulation predefined trains run on a railway network according to the timetable and under the constraints of the signaling system. Specialized software tool (OpenTrack), used to prepare, organize, run simulations and manage the outputs, can analyze and display the resulting data in the form of diagrams, train graphs, occupation diagrams and statistics. In this paper, simulation model, created in OpenTrack simulation tool, was used to measure train delays and unscheduled stops on a passing sidings of a single track railway line caused by train conflicts. Conclusions generated from this analysis could be used in strategic planning for determining infrastructure improvements of passing sidings on single track lines, but also in tactical planning for introducing timetable improvements regarding necessary station intervals and buffer times. Simulation model was generated and tested on a Serbian railways single track railway line between stations Stalać and Đunis.

Keywords: railway simulation, OpenTrack, passing siding, single track lines.

1. Introduction

Analysis of the train traffic is very important as an input to a process of planning in railways. Railway simulation is used to generate data on capacity of lines, train delays, train stops, energy consumption etc (Hansen and Pachl, 2014; Čičak, 2003). In last two decades many authors have used various simulation techniques, methods, programming languages or specialized software's to model railway traffic (Barber et al., 2007; Milinković et al., 2013; Jeremić et al., 2016; Milinković et al., 2015). One of the most commonly used tools for simulation of train traffic is OpenTrack. It is an object-oriented user-friendly tool for modeling in railways, develop to answer questions about railway operations by simulation (Nash and Huerlimann, 2004; Haramina et al., 2016). After a simulation run, OpenTrack can analyze and display the resulting data in the form of diagrams, train graphs, occupation diagrams and statistics. Due to the fact that the models can be easily created, and linked to the input and output sources, the OpenTrack software can be very important tool in the process of strategical, tactical, or operational planning (Milosavljević et al., 2014; Fischer et al., 2012).

We have created a simulation model of a railway traffic on a section of railway line Beograd – Niš – Preševo from Stalać to Đunis. The simulation model is used to evaluate the effects of the change in track layout when introducing various types of passing sidings on the existing infrastructure. Three different infrastructure layout solutions for passing sidings were analyzed. We have created the simulation model in OpenTrack simulation tool, and used it to measure train delays and unscheduled stops on a passing sidings of a single track railway line caused by train conflicts.

2. OpenTrack simulation software

OpenTrack was developed at the Swiss Federal Institute of Technology's Institute for Transportation Planning and Systems (ETH IVT). Figure 1 illustrates the three main elements of OpenTrack: data input, simulation, and output.

OpenTrack is a microscopic synchronous railroad simulation model. As such it simulates the behavior of all railway elements (infrastructure network, rolling stock, and timetable), as well as all the processes between them. It can be easily used for many different types of projects, including testing the stability of a new timetable, evaluating the benefits of different long-term infrastructure improvement programs, and analyzing the impacts of different rolling stock.

[2] Corresponding author: s.milinkovic@sf.bg.ac.rs

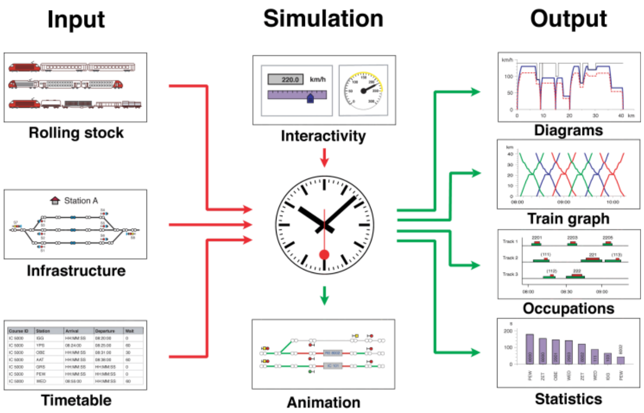


Fig. 1.
Data flow in simulation of railway operation

2.1. Input Data

OpenTrack manages input data in three modules: rolling stock (trains), infrastructure, and timetable. Users enter input information into these modules and OpenTrack stores it in a database structure. Once data has been entered into the program, it can be used in many different simulation projects. Similarly, different segments of the infrastructure network can be entered separately into the database and then used individually to model operations on the particular segment or together to model larger networks. Train data (locomotive and wagons) is entered into the OpenTrack database with easy to use forms displayed using pull down menus. Infrastructure data (e.g. track layout, signal type/location) is entered with a user-friendly graphical interface; quantitative infrastructure data (e.g. elevation) is added using input forms linked to the graphical elements, and timetable data is entered using forms (including shortcuts that enable data input to be completed efficiently).

2.2. Simulation

In order to run a simulation using OpenTrack the user specifies the trains, infrastructure and timetable to be modeled along with a series of simulation parameters (e.g. animation formats) on a preferences window. During the simulation, OpenTrack attempts to meet the user-defined timetable on the specified infrastructure network based on the train characteristics. OpenTrack uses a mixed continuous/discrete simulation process that allows a time driven running of all the continuous and discrete processes (of both the vehicles and the safety systems) under the conditions of the integrated dispatching rules.
The continuous simulation is dynamic calculation of train movements based on Newton’s motion formulas. For each time step, the maximum force between the locomotive’s wheels and the tracks is calculated and then used to calculate acceleration. Next, the acceleration function is integrated to provide the train’s speed function and is integrated a second time to provide the train’s position function.
The discrete simulation process models operation of the safety systems; in other words, train movements are governed by the track network’s signals. Therefore, parameters including occupied track sections, signal switching times, and restrictive signal states all influence the train performance.
OpenTrack is a dynamic rail simulation program. As such, the simulated operation of trains depends on the state of the system at each step in the process as well as the original user-defined objective data (e.g. desired schedule). A simple way of describing dynamic rail simulation is that the program decides what routes trains use while the program is running. Finally, dynamic simulation enables users to run OpenTrack in a step-by-step process and monitor results at each step. Users can also specify exactly what results are displayed on the screen. Running in a step-by-step mode with real time data presented on screen helps users to identify problems and develop alternative solutions.

2.3. Output

One of the major benefits of using an object-oriented language is the great variety of data types, presentation formats, and specifications that are available to the user. During the OpenTrack simulation each train feeds a virtual tachograph (output database), which stores data such as acceleration, speed, and distance covered. OpenTrack allows users to present output data in many different formats including various forms of graphs (e.g. time-space diagrams), tables, and images. Similarly, users can choose to model the entire network or selected parts, depending on their needs.

3. Simulation model of track section with passing sidings

In order to evaluate different solutions for passing sidings, three models of a section of railway line Beograd – Niš – Preševo from Stalać to Đunis were created. Models represent the passing sidings track layout variants.

3.1. Single track section Stalać – Đunis

Single track section Stalać – Đunis is a part of a mainline Beograd – Niš between km 176+311 and km 194+940. On this section there are two passing sidings, Stevanac and Staro Trubarevo, one station Braljina and one stopping point, Cerovo – Ražanj. Whole section is equipped with automatic block signaling and traffic is controlled from dispatching center Niš. Train speeds on this section are not impressive and their range is from 65 km/h between Stalać and Braljina and 85 km/h between Braljina and Đunis. In reality there are many speed restrictions with maximum speed from 30 km/h to 50 km/h. Passing siding Stevanac is located at km 181+900, it has two tracks, one main track and one siding, length of both tracks is around 700 m. It is situated in a sharp curve near Južna Morava River. Station Braljina is located at km 186+486,5, it has four tracks with approximate length around 650 m. Passing siding Staro Trubarevo is located at km 192+216, it has two tracks, one main and one siding which are around 712 m long. All stations are equipped with relay interlocking devices and are controlled remotely from dispatching center Niš. None of these stations are equipped for simultaneous entrances of two trains arriving from opposing direction.

3.2. Model of up-to-date track layout

Model of existing infrastructure was created using current data with some approximations (Figure 2). Some dead end tracks were not included in the model, and train speeds were used from current timetable. Sections with restricted speed were not included in the simulations, although some of them exist for a number of years.

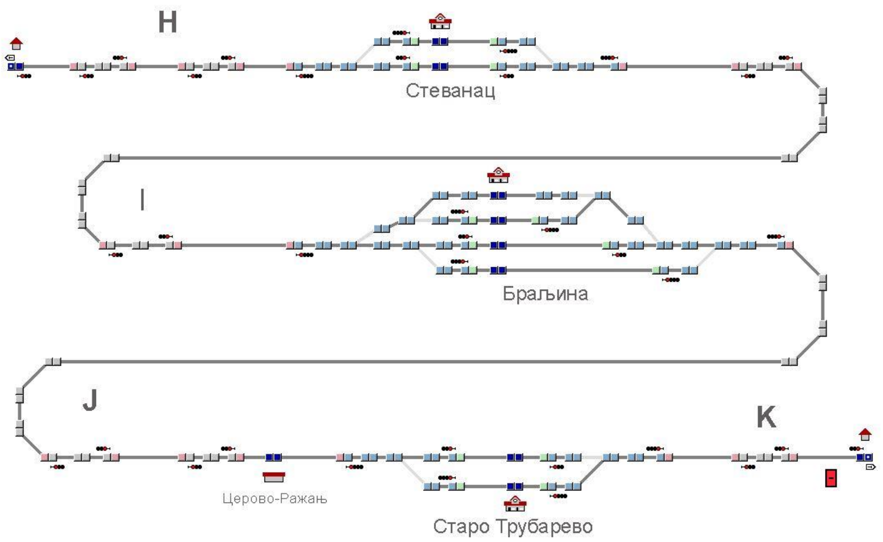


Fig. 2.
Model of current infrastructure

For this model, 2015/2016 timetable was used, but, since timetable for this line has a low number of trains, we have added 8 more passenger and 60 more freight trains, so that model could be tested in more difficult conditions.

3.3. Model with modified passing sidings

In model with modified passing sidings two modifications were performed on passing sidings infrastructure. First modification was performed in Stevanac with (track) block signals placed in front of exit signals and second was performed in Staro Trubarevo with dead end track on each end of the station. Those two solutions were compared with current infrastructure solution, but also compared to each other. Main goal of each modification was to enable simultaneous entrances of two trains from opposing direction, but at the same time their track length should be sufficient to accommodate longest train allowed on this line.

In passing siding Stevanac modifications were performed by placing block signals 50 m in front of each exit signal. This modification enables simultaneous entrances of two trains when route from each direction is set only to block signal. When route is set to exit signal, route overlap leads over entrance switch and forbids entrance of a train from other side. Same modifications were performed on station Braljina, block signal were placed 50 m in front of each exit signal on track two, three and four. On other hand, these modifications shortened useful length of tracks in both stations for 100 meters, although they are still longer than required for longest train on this section. Modifications on passing siding Staro Trubarevo were more extensive and, instead of block signals, four short dead end tracks were built. That operation required installment of four new switches, and consequently shortening both track for approximately 107 meters.

When comparing solutions applied in passing sidings Stevanac and Staro Trubarevo, it can be seen that infrastructure solution applied in Stevanac is more favorable in terms of useful track length and required investment costs and solution for Staro Trubarevo is more favorable in terms of safety. Useful length of track in Stevanac after modification is longer than in Staro Trubarevo for approximately 50 m, but also investments in four block signals are much lower than investments in four new switches and approximately 200 m of dead end tracks. Model with modified passing siding is shown in Figure 3.

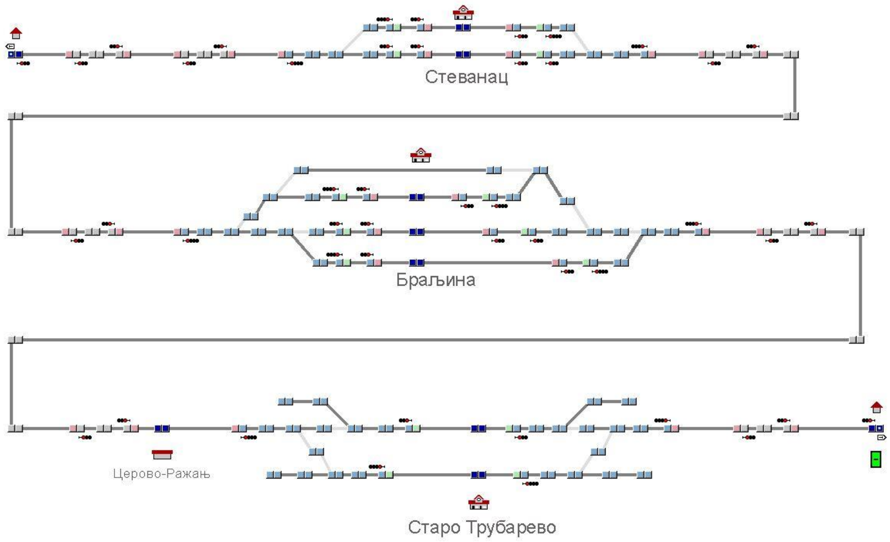


Fig. 3.
Model with modified passing sidings

3.4. Model with long passing sidings

In model with long passing sidings, sidings Stevanac and Staro Trubarevo were modified in a way that their track length was doubled. Goal was to create a siding which was long as two shortest 1000 m block sections. In order to minimize investment costs, sidings were extended on only one side, so only one switch was required to move. Criterion for siding extension was to extend it in the direction of longer track section between stations. Two variants of long passing sidings were created, one with crossovers in the middle and another without crossovers. For passing siding Stevanac second variant without crossovers was chosen. Reasons lay in fact that passing siding Stevanac is located on difficult terrain and in sharp curve, which would create difficulties in building and maintaining crossovers. Since track section between Stalać and Stevanac is longer than track section between Stevanac and Braljina, siding was extended in the direction of Stalać. Another problem was tunnel “Stevanac” located between switch number one and entrance signal. Since new crossovers would be located in the middle of the tunnel, solution without crossovers was chosen. Passing siding Staro Trubarevo is located in less difficult terrain so solution with double crossovers was chosen. Since track section between Braljina and Staro Trubarevo is longer than section between Staro Trubarevo and Đunis, siding was extended towards Braljina.

Another consequence of siding extension was reduction of both number and lengths of block sections between stations. Main criteria for shortening block sections were that block section length of first and last block section would not be shortened since they already have shortest allowable length and that minimum block section length for other sections should be 950 m. Between Stalać and Stevanac number of block was not reduced but length of second block section from Stalać was shortened. Between Stevanac and Braljina block lengths and number of block sections remained the same. Between Braljina and Staro Trubarevo shortening of existing block sections led to insufficient block lengths, therefore one block section needed to be removed. Remaining two block sections evenly divided track section between these two stations. Between Staro Trubarevo and Đunis block sections remained the same, both in number and lengths. Model with long passing sidings is shown in Figure 4.

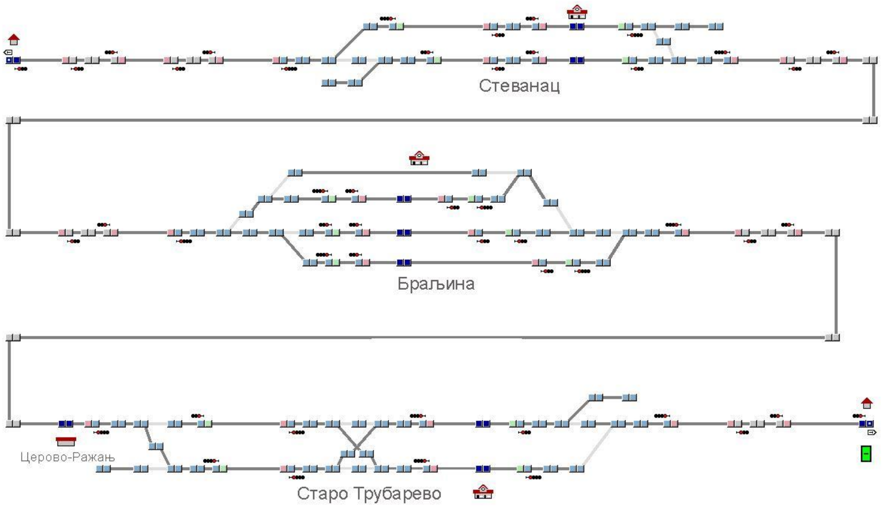


Fig. 4.
Model with long passing sidings

4. Simulation model results

There are number of output files which OpenTrack generates during simulations (Figure 5). Some files contain global information about whole simulation while others contain information about particular train or track section. In this case, purpose of these models was to determine impact of different infrastructure solutions of passing sidings on traffic flow. For this comparison three criteria were used: number of stops in front of entrance signal, number of speed reductions caused by red light on entrance signal and number of passes by distant block signal on “caution, expect stop” i.e. yellow light. All information were obtained from file OT_Messages.txt which includes all warnings and messages which appear during simulation. Number of stops in front of entrance signal was chosen as a criterion mainly because main goal of projected infrastructure solutions was to enable simultaneous entrances of opposing trains in siding. Concerning the fact than main reason for stopping trains in front of an entrance signal is lack of possibility for simultaneous entrances, infrastructure solutions which allow simultaneous entrances would at the same time decrease number of stops in front of entrance signal. Since same timetable was used for all three simulation models, by comparing data for the same trains it can be concluded how much number of stops varies from one variant to other. Part of file OT_Messages.txt edited in Excel is shown on Figure 6.

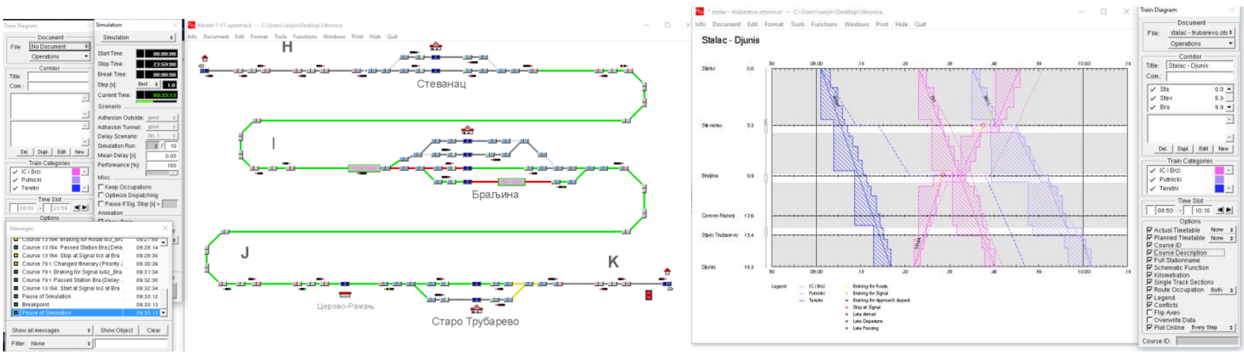


Fig. 5.
Outputs and results of the OpenTrack simulation model

NORMAL	0:22:00	59900	Ready	for	Simulation		
NORMAL	0:22:00	59900	Departure	at	Dju		
NORMAL	0:23:00	52267	Ready	for	Simulation		
NORMAL	0:23:00	52267	Departure	at	Sta		
NORMAL	0:24:12	59900	Passed	Station	Tru	(Delay-108s)		
NORMAL	0:25:33	59900	Passed	Station	CeR		
NORMAL	0:27:36	59900	Passed	closed	Distant	Signal	Ju91_Bra
NORMAL	0:27:41	59900	Braking	for	Speed	Reduction	Bra_[525]
NORMAL	0:27:53	52267	Passed	Station	Stev	(Delay-67s)	
WARNING	0:28:18	59900	Braking	for	Route	Io3_Bra	
NORMAL	0:28:34	59900	Passed	Station	Bra	(Delay-1646s)	
WARNING	0:28:50	59900	Stop	at	Signal	Io3	at	Bra

Fig. 6.
Part of OT_Messages.txt file

4.1. Number of stops in front of entrance signals

In regular operating conditions when all trains are running on time, stoppings in front of the entrance signal or passing by distant signal which shows “caution, expect stop” are not planned. If these events occur, they unnecessarily prolong travelling times and decrease traffic flow. Therefore, certain station buffer times are always planned and included in the timetable so that trains would not be stopped or slowed down in front of entrance signal. Since all three models are using the same timetable without delays, stoppings in front of entrance signals should not occur. On the other hand running times which are included in current year timetable used in simulations are not shortest running times since they include large time reserve caused by poor track condition. During simulation, OpenTrack calculates running times by dividing block length with maximum block speed which results in a shorter running times than those included in the timetable. Shorter running times lead to different arrival times in stations which in turn lead to shorter time differences between opposing trains. And in some cases those shorter time differences could lead to stopping of one train if there is no possibility for simultaneous entrances. These conditions actually lead to more realistic operating conditions in which freight trains are rarely following strict schedule. Number of stops in front of entrance signals for each of three variants and all stations are shown in table 1.

Table 1
Number of stops per entrance signal

Station / Passing siding	Entrance signal	Number of stopped trains		
		V1	V2	V3
Stevanac	Hu92	8	1	-
	Iu91	5	3	4
Braljina	Iu92	4	2	5
	Ju91	8	6	6
Staro Trubarevo	Ju92	7	-	9
	Ku91	5	-	-
Total		37	12	24

As it can be seen from Table 1 number of stops at siding Stevanac and station Braljina significantly decreased in second variant with block signals compared with current condition model, and at Staro Trubarevo in second variant there were no stops at all. Reasons lay in fact that in variant two Staro Trubarevo was equipped with dead end tracks, and that route overlap behind exit signals always led to dead end tracks, which enabled simultaneous entrances at all times.
In third variant with long sidings there were also less stops than in first variant with current conditions, but in some cases slightly more than in second variant with modified sidings. Therefore, third variant requires deeper analysis using some other criteria.
Second observed criterion was number of trains which are slowing down in front of entrance signal. Results are shown in table 2.

Table 2
Number of trains which slowed down in front of entrance signal

Station / Passing siding	Entrance signal	Number of stopped trains		
		V1	V2	V3
Stevanac	Hu92	9	9	-
	Iu91	6	3	5
Braljina	Iu92	6	10	8
	Ju91	13	11	16
Staro Trubarevo	Ju92	10	1	16
	Ku91	6	-	-
Total		50	34	45

Results show than number of trains which slow down in front of entrance signal is larger than number of trains which stop in front of same entrance signals. Further analysis confirmed that same trains which stopped in front of entrance signal also slowed down in front of the same signal. That also proved that there are few new trains which slowed down in front of entrance signal, but did not stop. In both passing sidings Stevanac and Staro Trubarevo number of trains slowing down is lower than in first variant. In third variant in some case there were more trains slowing down, even more than in first variant of current condition. Third criterion was number of trains which passed by distant block signal with aspect „caution, expect stop“, which are shown in table 3.

Table 3
Number of trains which passed on „caution, expect stop"

Station / Passing siding	Distant signal	Number of stopped trains		
		V1	V2	V3
Stevanac	H32	13	9	-
	I21	8	3	5
Braljina	I32	13	9	-
	J21	13	11	8
Staro Trubarevo	J32	10	1	16
	K21	6	-	-
Total		63	33	29

Results show than number of trains which passed by distant block signal with aspect „caution, expect stop" is even larger than number of trains which stop in front of corresponding entrance signals. That indicates that there are trains which passed distant signal on yellow, but did not stop at the entrance signal because of signal change to some other aspect different than red. This criterion also favors second variant over first and shows some improvement, while in variant 3 improvement are more pronounced and in some cases there were no trains which passed distant signal on yellow, which is considered optimal operating condition.

5. Conclusion

In comparison with existing track layout variant, model with modified passing sidings showed significant improvement with reduction of stops and delays on entrance signals. Variant with dead end track showed better results than the one with block signals. In comparison with existing track layout model, model with long siding gives shorter and less occurring stops, but not in all cases. Simulation results generated from OpenTrack simulation models provided enough information about effect of different infrastructure solutions of passing sidings. Consequently, it can be concluded that modified passing siding with dead end tracks or block signals provide enough improvement over classical sidings. To form more detailed conclusion on which of these two solutions has more advantages it requires to run more extensive simulation with experimenting with train delays scenarios and for the various timetable inputs. Also, simulation should be just one of the inputs along with safety and economical parameters for the further analysis (multicriteria decision making or optimization approach). Solution with long passing siding also showed improvement over current condition, but not significantly compared to the variant with modified passing sidings. General conclusion can be that the modified and long passing sidings have lots of advantages over classical sidings and they should be considered when single track railway lines are built or reconstructed.
Further research on the effects of passing sidings on train traffic could benefit from this research by applying the same simulation modelling approach. Depending on the goal of the research various simulation scenarios could be generated. For example, simulation could be used in strategic planning for determining infrastructure improvements of passing sidings on single track lines, but also in tactical planning for introducing timetable improvements regarding necessary analysis of train delays, station intervals and buffer times, etc.

Acknowledgments

This paper is supported by The Ministry of Educations and Science of the Republic of Serbia, within the research projects No. 36012.

References

Barber, F.; Abril, M.; Salido, M.A.; Ingolotti, L.; Tormos, P.; Lova, A. 2007. Survey of automated Systems for Railway Management, *Technical Report DSIC-II/01/07*. Technical University of Valencia.
Čičak, M. 2003. Modeliranje u železničkom saobraćaju. Saobracajni fakultet, Beograd.
Fischer, U.; Mirković, S.; Milinković, S.; Schöbel, A. 2012. Possibilities for integrated timetables within the Serbian railway network, *Facta universitatis-series: Mechanical Engineering,* 10(2): 145-156.
Hansen, I.A.; Pachl, J. 2014. Railway timetabling & operations: analysis, modelling, optimisation, simulation, performance evaluation. Eurailpress, Hamburg.
Haramina, H.; Schoebel, A.; Aksentijevic, J. 2016. OpenTrack – A Tool for Simulation of Railway Networks. CETRA – 4th International Conference on Road and Rail infrastructure, Šibenik.
Jeremić, D.; Milosavljević, M.; Milinković, S.; Vesković, S.; Bundalo, Z. 2016. *Simulation of a railway mainline junction using High level Petri nets*. In: Konjović, Z., Zdravković, M., Trajanović, M. (Eds.) *ICIST 2016 Proceedings,* 1: 235-240.
Milinković, S.; Grubor, N.; Vesković, S.; Marković, M.; Pavlović, N. 2015. *Simulation model of a Single Track Railway Line*. In: Zdravković, M., Trajanović, M., Konjović, Z. (Eds.) *ICIST 2015 Proceedings,* 1: 121-126.

Milinković, S.; Marković, M.; Vesković, S.; Ivić, M.; Pavlović, N. 2013. A fuzzy Petri net model to estimate train delays, *Simulation Modelling Practice and Theory*, 33: 144-157.

Milosavljević, M.; Milinković, S.; Vesković, S.; Branović, I.; Aćimović. S. 2014. Analiza sistema Bg voza primenom simulacionog paketa OpenTrack. In *Proceedings of the YU INFO 2014*, Kopaonik, Srbija.

Nash, A.; Huerlimann, D. 2004. Railroad simulation using OpenTrack. *WIT Transactions on the Built Environment*, 74.

IMPROVING THE TRANSPORT CAPACITY OF THE INTERMODAL TRAIN AND TRACK BASED ON DIFFERENT TYPES OF WAGONS

Jaroslav Mašek[1], Juraj Čamaj[2], Ivan Belošević[3]
[1,2] University of Žilina, Faculty of Operation and Economics of Transport and Communication, Univerzitná 8215/1, 010 26 Žilina, Slovakia
[3] University of Belgrade Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11 000 Belgrade, Serbia

Abstract: The paper consist of the analysis of selected indicators of transport characteristics of intermodal wagons and compare intermodal wagons in terms of main characteristics. The paper deals with possibilities of increase intermodal train capacity by using the different types of railway wagon. In the first part is created a mathematical model to calculate the capacity of the train. The model is based on the main limiting parameters of the train - maximum number of axles per train, maximum gross weight of train, maximum length of train and mount of transported intermodal loading units. In the second part is the model applied to some different type of trains with different composition of the train set and different average weights of intermodal loading units and a train consisting of the different type of wagons. The result is to identify where the carrying capacity of the original trains are higher, respectively less than a capacity of train consisting of others type of wagons.

Keywords: transport capacity, intermodal transport, intermodal wagons.

1. Introduction

Selection of the appropriate transport means is a key element determining and conditioning factors of providing the quality transport service and satisfaction with the railway operator services. The railway operator may provide quality transportation services - to be flexible, reliable, have suitable prices, etc., however the final quality of the movement of goods from the departure place to the destination will always depend on the choice of the appropriate transport mean - rail wagon. Railway wagons are the most important part of mobile base the rail transport operation and are an essential means of making transport and the providing of transport services. Under the railway rolling stock we mean all railway vehicles, which are used for the safe movement of the persons and goods.
The loading capacity of train is number of wagons, TEUs or the mass of goods that can be transported by one train. This paper works with model of the capacity converted on number of TEUs. The basic assumption is that using special long wagon will increase total capacity per train.
This paper consists of two parts:

- Theoretical model – general characteristics of relationships and formulas;
- Application of the model on selected model trains with use of common wagons for intermodal transport and with use of special long wagons.

2. Indicators of the transport characteristics of cargo rail wagons

Transport characteristics of cargo rail wagons is quantitative and qualitative expression of their ability to safely transport goods from the departure place to the destination and is conditioned mainly by designing every type of wagons as well as their use and composition of the wagon fleet and composition of different types of transported goods. Indicators of the transport characteristics are divided into three groups:

A. base indicators of wagon loading capacity,
B. own parameters of the transport characteristics,
C. comprehensive indicators of using the rolling stock fleet.

A. Base indicators of wagon loading capacity are based on the main technical characteristics of the wagon. These are the indicators of the technical possibilities of the use of the loading capacity of the wagon and also depending on the capacity of other parts of the railway infrastructure, for example railway lines. The base indicators include, in particular loading width, length, height, area and space. Also included loading capacity wagon, load per axle, wagon own weight (tare) and the weight per wagon length. Base indicators of wagon loading capacity are usually marked directly on the wagon through internationally standardized signs.

B. Own parameters of the transport characteristics value every elements of wagon ability to transport the goods and show dependencies between these elements that determine the possibility of using different types of wagons in terms of shipments by type and character of the goods. Own indicators of the transport characteristics include:

- the technical coefficient tare,
- the loading coefficient tare,
- the dynamic coefficient of tare.

[1] Corresponding author: Jaroslav.Masek@fpedas.uniza.sk

The technical coefficient tare expresses weight ratio of the own wagon weight (tare) and wagon´s loading weight. This coefficient characterizes the constructional quality of the wagon design. As smaller this value is, the better is constructional quality of the wagon. The technical coefficient tare reaches the relatively high values in case of wagon with special construction equipment.
The loading coefficient tare expresses weight ratio of the own wagon weight (tare) and weight of the actually transported goods. When calculating the load coefficient tare must take into account all types of goods for which the wagon is designed and frequency of transportations. This coefficient is inversely dependent on the loading wagon weight. Loading capacity is the best used in case of wagon with special construction, for the universal wagons is this coefficient is less.
Dynamic coefficient of tare reflects the use of the loading capacity of wagon with respect to the empty wagon´s runs.

C. Comprehensive indicators of using fleet capacity deals with ability of wagon to transport in the conditions of specific configuration of the rolling stock, in condition of all types of goods and the organization and operation of the transport technology. Among the indicators of comprehensive of using rolling stock fleet capacity are:

- the average static using of loaded wagon unit,
- the average dynamic using of the loaded wagon unit,
- the average dynamic using of wagon unit of rolling stock fleet.

Except the previous indicators of the transport characteristics cargo wagon there are others characteristics according to we can be distinguished wagons. Others transport characteristics include:

- the ratio of the maximum loading weight and wagon´s tare,
- the ratio of the loading weight and loading length of the wagon,
- loaded weight ratio and wagon length over buffers,
- unused (dead) loading length of wagon,
- the maximum loading weight per meter of the wagon,
- unused loading capacity for D tracks categories,
- dependence of the maximum loading weight per meter of the wagon and the wagon length over buffers.

3. The possibility of increasing the transport capacity of railway infrastructure

Increasing the capacity of rail infrastructure can be done in several ways, including:

- construction and reconstruction work:
  - to increase the line speed,
  - the construction of double track inserts for flying cruising and overtaking,
  - the double-tracking railway section,
  - the electrification,
- change in the organization of train traffic:
  - in the freight railway transport exists possibility of the implementation of new methods for the development of freight trains (time-discrete forming of trains) reflected in the plan of train formatting,
- increase train capacity:
  - by appropriate choice of the composition of cargo wagons in each train.

This choice of suitable cargo wagons in train set is one of the least expensive way of increasing the capacity of rail infrastructure.

4. Calculation of the maximum number of TEU unit in train

Maximum number of TEUs transported in train depends on the train parameters – length, weight and number of axles normative. The number of TEUs per train is limited by:

- maximum number of axles per train,
- maximum gross weight of train,
- maximum length of train,
- number of TEUs per one wagon.

4.1. Number of axles per train limitation

Maximum number of TEUs depending on normative of axles per train is calculated according to the following relation:
General relationship:

$$N_{TEU}^{max/train} = \frac{N_{axles}^{max/train} - N_{axles}^{Locomotive}}{N_{axles}^{wagon}} . N_{TEU}^{max/wagon} \quad (1)$$

where:
$N_{axles}^{max/train}$ - maximum number of axles per train (axles),
$N_{axles}^{Locomotive}$ - number of locomotive axles (axles),
N_{axlex}^{wagon} - number of axles per wagon (axles),
$N_{TEU}^{max/wagon}$ - maximum number of TEUs on wagon (TEU).

This equation can be edited for common wagon for intermodal transport and for special long wagon. Common wagon for intermodal transport (wagon type Sgnss) can carry maximum 3 TEUs. Special long wagon can carry maximum 4 TEUs.
Formula edited for common 4 – axle wagon (type Sgnss):

$$N_{TEU}^{max/train} = \frac{N_{axle}^{max/train} - N_{axle}^{Locomotive}}{4} . 3 \tag{2}$$

where:
$N_{axle}^{max/train}$- maximum number of axles per train (axles),
$N_{axles}^{Locomotive}$ - number of locomotive axles (axles).

Formula edited for special long wagon:

$$N_{TEU}^{max/train} = \frac{N_{axles}^{max/train} - N_{axles}^{Locomotive}}{4} . 4 = N_{axles}^{max/train} - N_{axles}^{Locomotive} \tag{3}$$

where:
$N_{axle}^{max/train}$– maximum number of axles per train (axles),
$N_{axles}^{Locomotive}$ – number of locomotive axles (axles).

4.2. Maximum train weight limitation

Maximum gross weight of train is depending on the type of locomotive, on the line parameters and the vehicle resistances. It is set in the prescriptions for each line, type of locomotive and used wagons. Maximum number of TEUs per train limited by maximum gross weight of train is calculated by following formulas:

$$N_{TEU}^{max/train} = \frac{M_{train}^{max} - M_{Locomotive}}{M_{wagon}^{tarra} + N_{wagon}^{\emptyset,TEU} . M_{TEU}^{\emptyset}} . N_{wagon}^{\emptyset,TEU} \tag{4}$$

where:
$N_{TEU}^{max/train}$ – maximum number of TEUs in train (TEU),
M_{train}^{max} – maximum gross weight of train (tons),
$M_{Locomotive}$ – locomotive weight (tons),
M_{wagon}^{tarra} – net weight of wagons (tons),
$N_{wagon}^{\emptyset,TEU}$ – average number of TEUs on wagon (TEU),
$M_{TEU}^{\emptyset}$ – average TEU weight in train (tons), while following requirement is valid:

$$M_{TEU}^{\emptyset} \leq M_{TEU}^{max} \tag{5}$$

4.3. Maximum weight of TEU limited by the type of wagon

Maximum weight of TEU is limited by the axle load. It is calculated by following equation:

$$M_{TEU}^{max} = \frac{N_{axles}^{wagon} . M_{axles}^{max} - M_{wagon}^{tarra}}{N_{TEU}^{wagon}} \tag{6}$$

where:
M_{TEU}^{max} – maximum gross weight of TEU (tons),
N_{axles}^{wagon} – number of wagonaxles (axles),
M_{axle}^{max} – maximum axle load (tons):

A – 16,0tons/axle B – 18,0 tons/axle
C – 20,0 tons/axle D – 22,5 tons/axle

M_{wagon}^{tarra} – net wagon weight (tones),
N_{TEU}^{wagon} – number of TEU on the wagon (TEU).

4.4. Maximum train length limitation

The limitation of overall length of train depends on the length of the shortest station track intended for transport (not shunting tracks). This maximum length of train is set in the prescriptions for each line [12]. Maximum number of TEUs per train limited by maximum train length is calculated by this equation:

$$N_{TEU}^{max/train} = \frac{(L_{trai}^{max} - L_{Locomotive})}{L_{wagon}} . N_{TEU}^{max/wagon} \tag{7}$$

where:
$N_{TEU}^{max/train}$ – maximum number of TEU on the train (TEU),
L_{train}^{max} – maximum train length (m),
$L_{locomotive}$ – locomotive length (m),
L_{wagon} – total wagon length (m),
$N_{TEU}^{max/wagon}$– maximum number of TEUs on the wagon (TEU).

4.5. Limitation by the number of TEUs per 1 wagon

Number of TEUs that can be loaded on one wagon is given by loading length and the construction of the wagon.
Conversion TEU units: 1 ISO 1C container = 1 TEU (20)

$$N_{TEU} = \frac{L_{cont}}{20'} \tag{8}$$

where:
N_{TEU} – container length recomputed on number of TEUs,
L_{cont} – container length (feet).

4.6. Conclusion of the model

The final maximum number of TEUs in the train is the lowest number from these:

- number of TEUs per train depending on maximum number of axles per train,
- number of TEUs per train depending on maximum gross weight of train,
- number of TEUs per train depending on maximum length of train,

and given by the minimum value of the maximum number of TEUs resulting from:

- maximum number of axles in train,
- maximum train weight,
- maximum train length.

Capacity means the number of TEUs per train:

$$N_{F-TEU}^{max/train} = min\{N_{i,TEU}^{max/train}\} \tag{9}$$

where:
$N_{F-TEU}^{max/train}$ – final maximum number of TEUs in the train (TEU);
$N_{i,TEU}^{max/train}$– maximum number of TEUs in the train computed through max. number of axles per train, max. train weight and max. train length (TEU).

5. Calculation of maximum transported goods mass and transport performance of one train

In this calculation we assume from the estimated number of TEUs per train. Input for the calculation is the average load of one TEU ($M_{good}^{\emptyset/TEU}$).
Calculation of maximum transported goods mass and transport performance of one train:

$$M_{good}^{max/train} = N_{F-TEU}^{max/train} \times M_{good}^{\emptyset/TEU} \tag{10}$$

where:

$M_{goods}^{max/train}$ – maximum quantity of goods transported by one train (tons),
$N_{F-TEU}^{max/train}$ – maximum number of TEUs transported by train (TEU),
$M_{good}^{\emptyset/TEU}$ – average load of one TEU (tons).

6. Applications of the model on the selected type of trains with the use of common wagons for intermodal transport and with the use of special long wagon

Application of the model is processed for different variants of model train. We processed separately the analysis of train capacity increase depending on maximum train length, maximum number of axles in the train and maximum train gross weight normative.
Calculations are processed via comparison of train with several possible combinations of the wagon compilation and the block train that consist of special long wagon. We realized the calculations for these concrete types of trains:

- block train consisting of the Sgnss wagons,
- block train consisting of the Lgs wagons,
- intermodal transport train set up according to wagon list of actual intermodal transport train which operates on the route Koper (SI) – Zilina (SK).

These wagon compilations are compared with the block train set up from the special long wagons. In the calculations average gross weight of one TEU is considered 11.7 tons. When considering maximum load capacity usage of special long wagon (in chosen variants), then gross weight of one TEU is 16.5 tons. When we compare with the train on route Koper – Zilina, we consider the real average weight of one TEU is 5.9 tons.

Inputs of the Model
Next Tables 1-5 are input data for capacity model.

Table 1
Wagon type Sgnss and Lgs - technical data

		Sgnss	Lgs
Number of axles		4	2
Overall length		19.740 m	14.02 m
Tara weight		19.800 t	10.80 t
Loading weight	A	44.20 t	21.30 t
	B	52.20 t	25.30 t
	C	62.20 (60.20) t	29.20 t
	D (120 km/h)	70.20 (60.20) t	-
Loading length		18.500 m	12.78 m

Source: (authors)

Table 2
Example of wagon list of real intermodal transport train which operated on the route Koper (SI) – Zilina (SK)

	Wagon type	Mount of wagon	Weight (kg)		Overall length	Number of axles	TEUs on wagon
			netto	tara	(m)	(axels)	(m)
1	Kgs	18	181,041	232,060	13.9	2	2
2	Sggmrss	1	30,249	29,000	29.5	6	4
3	Laags	5	13,4717	111,960	27.8	4	4
4	Kbkks	3	29,151	37,000	13.9	2	2
5	Regs	1	20,117	23,550	13.9	2	2
6	Kbgs	1	7,058	13,000	27.8	4	4
7	Sgnss	2	53,343	38,850	13.9	2	2
Total		31	455,676	485,420	534,54	82	77
Locomotive			870,00		16.74	4	--

Source: (authors)

Table 3
Basic technical data of the special long wagon

Number of axles	4
Overall length	25.94 m
Tare weight	23.9 t

Source: (authors)

In the following calculation of capacity of train compare the four sets of intermodal transport trains with fixed parameters of the train. Train characteristics are - the length 750 m and gross weight of 2,000 t. Locomotive parameters - the length of 16.7 meters and weight of 80 tons. Track category D. The results of the calculations are shown in Table 4 and 5.

Table 4
Overview of the number TEU in the train by a combination of variants and weights of the TEU

	TEU weight (t)	Number of TEU in intermodal train (TEU)		Number of TEU in intermodal train according decisive criteria
		750 m	2,000 t	
Set Sngss – var 1	A – 5.9	111	153	111
Overall length 19.8 m	B – 11.7	111	105	105
Tara weight 19.74 t	C – 16.5	111	81	81
Various set – var 2				
Overall length 17.24 m	A	104	156	104
Tara weight 15.7 t	B	104	104	104
	C	104	81	81
Set Lgs – var 3				
Overall length 14.02 m	A	104	168	104
Tara weight 10.8 t	B	104	112	104
	C	104	70	70
Set of special long wagon – var 4				
Overall length 25.94 m	A	112	160	112
Tara weight 23.9 t	B	112	108	108
	C	112	84	84

Source: (authors)

Table 5
Overview of transport capacity of intermodal train (750 m and 2000 t) in every variant of train set

	Capacity of the train (TEU)		
	5.9 t/TEU	11.7 t/TEU	16.5 t/TEU
Var 1	111	105	81
Var 2	104	104	81
Var 3	104	104	70
Var 4	112	108	84

Source: (authors)

Previous calculations have shown that the composition of the set of wagons affects the transport capacity of the train. This change subsequently affects the transport capacity of rail infrastructure – railway track, which can be demonstrated by the following example. We choose double track with capacity of 100 trains in one direction per day. We will use the transport capacity of the previous model train composition variations (Table 5), calculate the capacity to track the number of TEU transported and get the Table 6

Table 6
Overview of track capacity calculation in every variant of train set

	Track section capacity (TEU)		
	5.9 t/TEU	11.7 t/TEU	16.5 t/TEU
Var 1	11,100	10,500	8,100
Var 2	10,400	10,400	8,100
Var 3	10,400	10,400	7,000
Var 4	11,200	10,800	8,400

Source: (authors)

If we want on model the track to transport the previous calculated amount TEU from trains of variants 1-3, by train with the highest capacity (option 4), we can see how much less train would we needed it. That means how many train routes would we have reduced the use of track capacity. The calculated data are provided in the number of trains (Table 7).

Table 7
Reduction of of necessary train, resp. using the tracks capacity

	Number of trains		
	5.9 t/TEU	11.7 t/TEU	16.5 t/TEU
Var 1	1	3	4
Var 2	8	4	4
Var 3	8	4	17

Source: (authors)

7. Conclusion

Table 5 shows the transport capacity of the model train (750 m, 2,000 t) depending on the train composition, which results in advantage of using special long wagons with a single loading area in the all variants.
Table 6 indicate that the maximum transport capacity of the track is in the composition of the model train by special long wagons with a single loading area in all variants.
Table 7 confirms increasing the transport capacity, resp. reducing the number of necessary trains and using the tracks capacity.
Proposed model of transport capacity of the train and railway track based on used types of wagons should optimize the track capacity without any special and expensive solutions and would improve efficiency of operation in transport service and thus contributing to overall satisfaction of customers. Application of the proposed model doesn´t have any special financial expenses, because needs only changing current system of operation.

Acknowledgements

The paper is supported by the VEGA Agency by the Project 1/0701/14 „Impact of liberalization of the rail freight market on the social costs of transport“, and project KEGA 026ŽU-4/2015: „Innovative approaches in system of teaching management in the study program Railway transport with a focus on application the dynamic quality models in the railway transport”, that are solved at Faculty of Operations and Economics of Transport and Communication, University of Žilina.

References

Čamaj, J.; Dolinayová, A. 2011. The organization of the wagon flows with respect to the economic criteria of railways companies. In *Proceedings of LOGI 2011: 12th international scientific conference,* November 24th, 2011 in Pardubice. Czech Republic - ISBN 978-80-263-0094-6. 140-148.

Černá, L.; Daniš, J. 2015. Comparison of costs and possibilities to increase train capacity on an appropriate choice of the wagon. In *Proceedings of Logistics - economics - praxis 2015: proceeding from 4th international scientific conference,* Žilina 8th December 2015. - ISSN 1336-5851. 2015. 12-20.

Dávid, A.; Sosedová, J.; Putz, L.M.; Jolie, N.; Kavran, Z. 2014. European automated container terminals. *In Proceedings of Communications: scientific letters of the University of Žilina.* - ISSN 1335-4205. 16(2): 41-45.

Fabián, P.; Márton, P.; Gerlici, J.; Mašek, J. 2014. Project VEL-Wagon - an example of successful cooperation of universities and industry. In *Proceedings of 10th Forum of rail transport: 18.-19.3.2014,* Bratislava: - Bratislava: FO ART, 2014. - ISBN 978-80-89664-08-5. 95-99.

Fabián, P.; Márton, P.; Gerlici, J.; Mašek, J. 2013. Versatile, efficient and long wagon for intermodal transport in Europe. In *Proceedings of Communications: scientific letters of the University of Žilina*. - ISSN 1335-4205. 15(2): 118-123.

Gašparík, J.; Meško, P.; Zitrický, V. 2010. Role of rail cargo companies in logistic chains. In *Proceedings of Railway logistics and rail cargo: proceedings of the 5th SoNorA University Think Tank Conference:* 17th of June 2010, (Erfurt). Erfurt: Institut Verkehr und Raum der Fachhochschule Erfurt, 2010. S. 19-26. ISSN 1868-8411.

Jagelčák, J.; Dávid, A. 2014. *Maritime transport and maritime containers*. - 1. ed. - Bytča: Druska Books as university textbook, 2014. - CD-ROM, 275 p., ISBN 978-80-89646-90-6.

Kendra, M.; Lalinska, J.; Čamaj, J. 2012. Optimization of transport and logistics processes by simulation. In *Proceedings of ISTEC: 3rd international science, technology and engineering conference,* December 13-14-15, 2012, Dubai, United Arab Emirates (UAE). - ISSN 2116-7383. 886-892.

Kendra, M.; Mašek, J.; Babin, M. 2014. Impact of railway infrastructure parameters on safety of goods transportation by railways. In *Proceedings of Machines, technologies, materials: international virtual journal.* - ISSN 1313-0226. 8, (3): 44-47.

Nedeliaková, E.; Dolinayová, A.; Nedeliak, I. 2013. *Methods of evaluation of the transportation services quality*. University of Žilina in Žilina, EDIS, ISBN 978-80-554-0817-0. 184 p.

Project 7th FP no. 265610: VEL Wagon, Deliverable 2.2. Available from Internet: <www.vel-wagon.eu>.

Skrúcaný, T.; Gnap, J. 2014. The effect of the crosswinds on the stability of the moving vehicles. In *Proceedings of Applied Mechanics and Materials.* - ISSN 1662-7482. 617: 296-301.

DECISION SUPPORT SYSTEM FOR FORECASTING THE NUMBER OF RAIL SLEEPING CARS

Marko Kapetanović[1], Milica Šelmić[2], Dragana Macura[3], Rešad Nuhodžić[4]
[1,2,3] *University of Belgrade - Faculty of Transport and Traffic Engineering, Serbia*
[4] *"MonteCargo" AD, Podgorica, Montenegro*

Abstract: The model developed in this paper predicts the number of required sleeping cars in rail transport during peak season and it is based on Artificial Neural Network. This decision support system has several relevant inputs: train route, month, type of sleeping car, number of berths (supply), number of departures, ticket price and GDP; while the output of the system is the number of sold tickets (demand). Additionally, with the aim of better understanding relationships between input and output data, different correlation tests are conducted. The correlation between input variables is tested using Pearson and Spearman rank correlation tests. Further the correlation between a group of inputs and output is tested using canonical correlation. Proposed model is useful especially for rail managers who should make appropriate decisions related to the sleeping cars capacity planning. All considered data are collected from Serbian Railways.

Keywords: prediction, rail sleeping cars, correlation analysis, artificial neural network.

1. Introduction

Prediction of demands on transport market is big challenge for every analyst or manager. The volume of transport demands is depending of many factors, and they can be: economical, sociological, demographical, technological factors, etc. In cases like this, where there are many heterogeneous factors influencing the output observed, classical methods such as regression may lead to inconsistent results. Thus, the implementation of Artificial Neural Network (ANN) is imposed as adequate approach in solving this problem.

In this paper the authors present the extension of the previous model for predicting the number of rail sleeping cars published in (Macura et al., 2015). The suggested model is based on real data from Public Enterprise "Serbian Railway". The inputs of the model are: train route, month, type of sleeping car, number of berths (supply), number of departures, ticket price and GDP; and the output of the system is the number of sold tickets (demand).

The main difference between (Macura et al., 2015) and this paper is in the application of different correlation tests, with the aim of better understanding relationships between input and output data. Correlation between variables is assessed using Pearson and Spearman rank correlation tests. Also the correlation between a group of inputs and output is tested using canonical correlation. The obtained degrees of correlation confirm that selected relevant elements and ANN approach are adequate for this purpose.

After the correlation between inputs and output in the model is tested, Artificial Neural Network model is presented with the purpose to predict the demands for rail sleeping cars.

The paper is organized as follows. After Introduction, in Section 2 correlation between variables is evaluated. Section 3 presents model based on ANN as well as obtained results. And forth, last, section, is dedicated to the conclusion and future research.

2. Correlation between used data

The problem analyzed in this paper is classified as a prediction problem. While doing a forecast, Artificial Neural Network predicts future values of the outputs for a range of inputs. The accuracy of estimate output data depends on many factors, but the most important are the number and relevance of the input data (Rasouli and Timmermans, 2012; Wardman, 2006).

In this paper, the inputs to the system consist of train route, month, type of sleeping car, number of berths, number of departures, ticket price and GDP. The output of the neural network is the number of tickets sold (demand) for sleeping cars (Macura et al. 2015).

We analyzed rail directions of the Serbian railway network from Subotica, Novi Sad and Belgrade to Bar, Montenegro. Data are from 2009 to 2013, including four months: June, July, August and September. Three types of rail cars equipped with berths are considered: couchette cars – Ac and Bc, and sleeping cars – WL.

[2] Corresponding author: d.macura@sf.bg.ac.rs

Table 1
Input data

Year	Train route	Month	Type of sleeping car	Number of berths (supply)	Number of depart.	Ticket price	GDP	Number of sold tickets (demand)
x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	y
2009	NS	June	Wl	1456	30	10467.52	42.9	750
2009	NS	July	Wl	1976	31	10399.2	42.9	1318
2009	NS	Avg	Wl	1664	31	10414.88	42.9	1409
2009	NS	Sept	Wl	1520	30	10522.4	42.9	519
2009	NS	June	Bc	3196	30	5981.44	42.9	1089
...	...			...		...		...
2013	Bg	June	Bc	324	90	6814.2	47.1	115
2013	Bg	July	Bc	2180	93	6814.8	47.1	995
2013	Bg	Avg	Bc	2160	93	6820.8	47.1	1495
2013	Bg	Sept	Bc	108	90	6852.6	47.1	81

2.1. Correlation analysis

Descriptive statistic of input and output variables are presented in Table 2.

Table 2
Descriptive statistics of variables

Variable	Description	Observations	Mean	Std.Dev.	Min	Max
x_1	Year	112	2011.054	1.413189	2009	2013
x_2	Train route	112	1.776786	0.6672496	1	3
x_3	Month	112	7.5	1.13899	6	9
x_4	Type of sleeping car	112	1.714286	0.7157	1	3
x_5	Number of berths	112	2532.473	1697.079	108	8464
x_6	Number of departures	112	66.96429	33.74785	30	124
x_7	Ticket price	112	9292.286	2470.737	5571	13438.55
x_8	GDP	112	45.7375	2.127601	42.9	48.6
y	Number of sold tickets	112	1665.938	1254.798	70	6426

The correlation between variables is evaluated using two widely used statistical tests – Pearson's and Spearman's rank correlation tests. The aim was to analyze the relationship between variables, thus in orders to obtain consistent results two commonly used tests were applied and the results are compared.

Pearson's correlation coefficient was discovered by Bravais (1846), but the first who described the standard method of its calculation was Karl Pearson (1896). Pearson's correlation coefficient represents a measure of the strength of the linear relationship between two variables. An important assumption regarding this correlation measure is the normality of the variables analyzed (Hauke and Kossowski, 2011).

In addition to Pearson's work, Spearman (1904) introduced new correlation measure between two variables. Spearman's rank correlation coefficient represents a nonparametric (distribution-free) rank statistic aiming to measure the strength of the (monotone) association between two variables.It is often used when the distribution of data makes Pearson's correlation coefficient misleading. Compared to Pearson's correlation coefficient, it does not represent the measure of linear relationship between two variables, but it assesses how well an arbitrary monotonic function can describe the relationship between two variables, without making any assumptions about the frequency distribution of the variables (Hauke and Kossowski, 2011).

Results of Pearson's and Spearman's correlation tests are presented in Tables 3 and 4. Both tests showed similar results. Considering statistically significant coefficients, both tests indicated relatively high correlation coefficients between input variables representing year (x1) and GDP (x8), as well as between type of sleeping car (x4) and ticket price (x7). Negative sign of the latest coefficient may be a consequence of arbitrarily assignment of numerical values to different types of sleeping car. Regarding output variable (y), which represents the number of sold tickets, both tests indicated high and statistically significant correlation between output variable and the input variable which represents number of berths (x5). All other coefficients have a relatively low value, are not statistically significant, or both.

Table 3
Results of Pearson's correlation test

Var.	x1	x2	x3	x4	x5	x6	x7	x8	y
x1	1								
x2	0.080	1							
x3	0.000	0.018	1						
x4	0.024	0.073	0.000	1					
x5	-0.227*	0.012	-0.045	-0.226*	1				
x6	-0.168	0.266**	-0.021	0.321**	0.326**	1			
x7	0.189*	0.085	-0.022	-0.615**	-0.050	-0.129	1		
x8	0.878**	0.059	0.000	-0.012	-0.233*	-0.212*	0.207*	1	
y	-0.136	-0.004	0.009	-0.221*	0.925**	0.288**	-0.015	-0.120	1

**Denotes statistical significance at level α=5%*
***Denotes statistical significance at level α=1%*

Table 4
Results of Spearman's rank correlation test

Var.	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	y
x_1	1								
x_2	0.071	1							
x_3	0.000	0.015	1						
x_4	0.035	0.085	0.006	1					
x_5	-0.147	0.007	-0.073	-0.062	1				
x_6	-0.165	0.315**	-0.020	0.265**	0.361**	1			
x_7	0.243**	0.072	-0.007	-0.681**	-0.227*	-0.155	1		
x_8	0.892**	0.058	0.000	0.001	-0.174	-0.170	0.294**	1	
y	-0.043	-0.035	-0.028	-0.129	0.847**	0.390**	-0.090	-0.058	1

**Denotes statistical significance at level α=5%*
***Denotes statistical significance at level α=1%*

Quantification of the intensity of dependence between two different sets of variables may be conducted by canonical correlation analysis (Kráľ and Roháčová, 2013). In addition to previous tests, this paper also aims to evaluate the dependence between the set of inputs, containing eight variables, and the set of outputs, which, in this case, consists of only one variable. For this purpose canonical correlation is used. Results are presented in Table 5. The raw canonical coefficients can be used to generate canonical varieties of input and output sets, and are interpreted in a manner analogous to interpreting regression coefficients. High value of canonical correlation coefficient indicated strong dependence between the set of inputs and the output.

Table 5
Canonical correlation analysis

	Variable	Coefficient
Raw coefficients for the first variable set	Y	0.001
Raw coefficients for the second variable set	x_1	-0.033
	x_2	-0.043
	x_3	0.050
	x_4	0.013
	x_5	0.001
	x_6	0.000
	x_7	0.000
	x_8	0.070
Canonical correlation		0.932

In order to test if a canonical correlation is statistically different from zero, different test are applied, and the results are presented in Table 6. Results confirmed that the obtained canonical correlation coefficient is statistically significant.

Table 6
Tests of significance of canonical correlation

Test	Statistic	F	Prob>F
Wilks' lambda	0.13068	85.6519	0.0000
Pillai's trace	0.86933	85.6519	0.0000
Lawley-Hotelling trace	6.65257	85.6519	0.0000
Roy's largest root	6.65257	85.6519	0.0000

3. Results of Artificial Neural Network Model

The Artificial Neural Network (ANN) is an approach that relies on a simplified brain model. The processing tasks are distributed over many neurons (nodes, units or processing elements). Even though individual nodes are capable of simple data processing, the main power of a neural network is the result of connectivity and collective behaviour between the nodes (Teodorović and Šelmić, 2012).
The ANN model is developed and presented with details in (Macura et al., 2015). The structure of the model, with all inputs and output, is presented in following figure.

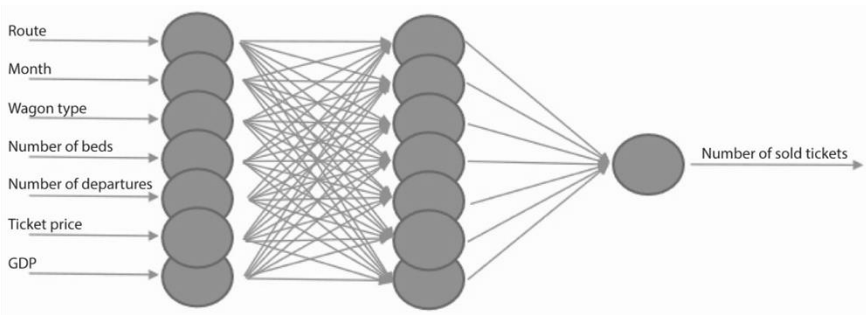


Fig. 1.
The structure of the ANN model

For the neural network, three types of patterns have been taken into consideration. The first data set represents the data which are used for the neural network training, and the network is consequently adapted in accordance with the mistakes made in this iteration. The second one is used for validation. These data are used to generalize the network, and to end training process at the moment when the neural network stops making further improvements. Finally, the third one is used for testing. This data set does not influence the training process, and by extension, it represents an independent measure of the neural network’s performance during and after the training. In our code, in Matlab, this pattern makes 24% of all data (Macura et al. 2015).
The model is developed in Matlab, and final results shows high correlation between output and target data (Figure 2).

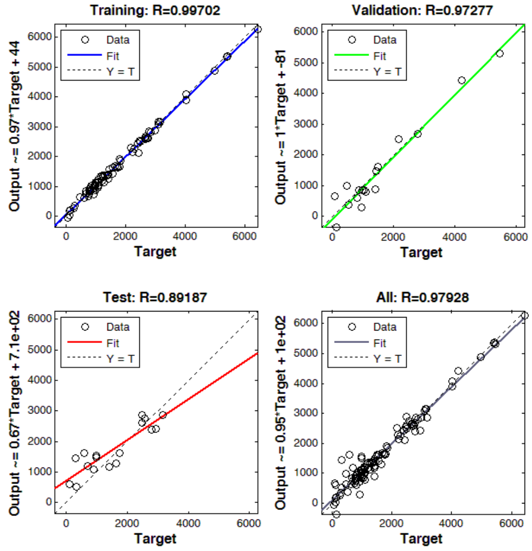


Fig. 2.
Relations between the output data and target results obtained by Matlab

As it can be seen from Figure 2 during the training phase, the artificial neural network has predicted the number of sold tickets, which reflects the reality in 99,7% of cases. When the test data were processed, an accurate prediction of the number of tickets sold was 89,2% in all cases. The regression in the case of test data is shown in Fig. 2, where the x-axis shows the target values (the number of tickets sold in the past), while the y-axis shows the output values (the number of tickets obtained by means of neural network's prediction).

4. Conclusions

The model presented in this paper forecast the number of rail sleeping cars, based on several relevant factors. For the first time, the correlation between inputs and output of the model is tested, and the obtained correlation coefficients confirmed the relevance of all considered factors and the validity for using ANN in solving the problem. The model for prediction is based on the ANN, and the model is tested on the real data from PE "Serbian Railways".
There are some also relevant factors, such as: civil standard, the quality of service, etc., which can be considered and relatively easily included in the model. Uncertainty and imprecision of such inputs values can be considered by using the fuzzy sets. The authors' future researches are related to this kind of solutions.

Acknowledgements

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through the projects TR36002 and TR36022 for the period 2011-2016.

References

Bravais, A. 1846. Analyse mathématiquesur les probabilités des erreurs de situation d'un point, *Mémoires présentés par divers savants à l'Académie Royale des Sciences de l'Institut de France*, 9: 255-332.
Hauke, J.; Kossowski, T. 2011. Comparison of Values of Pearson's and Spearman's Correlation Coefficients on the Same Sets of Data, *Quaestiones Geographicae*, 30(2): 87-93.
Kráľ, P.; Roháčová, V. 2013. Measuring the Efficiency of Public Road Transport Companies in the Slovak Republic using DEA and SFA, *Statistika: Statistics and Economy Journal*, 93(2): 76-85.
Macura, D.; Šelmić, M.; Dimitrijević, B.; Miletić, M. 2015. Neural network based model for predicting the number of sleeping cars in rail transport, *International Journal for Traffic and Transport Engineering*, 5(1): 29-35.
Macura, D.; Šelmić, M.; Teodorović, D.; Miletić, M. 2014. Model za predikciju broja spavaćih kola u železničkom saobraćaju primenom neuronskih mreža, Symopis, Divčibare, Srbija, 637-642.
Pearson, K. 1896. Mathematical contributions to the theory of evolution. III. Regression, heredity, and panmixia, *Philosophical Transactions of the Royal Society Ser. A*, 187: 253-318.
Rasouli, S.; Timmermans, H. 2012. Uncertainty in travel demand forecasting models: literature review and research agenda, *Transportation Letters*, 4.1: 55-73.
Spearman, C.E. 1904. The proof and measurement of association between two things, *American Journal of Psychology*, 15: 72-101.
Teodorović, D.; Šelmić, M. 2012. Računarska inteligencija u saobraćaju, Saobraćajni fakultet, Beograd.
Wardman, M. 2006. Demand for rail travel and the effects of external factors, *Transportation Research Part E*, 42: 129-148.

PREDICTIVE MODEL OF VIBRATIONS INDUCED BY RAILWAY TRANSIT IN URBAN AREAS

Manuela Esposito[1], Laura Mancini[2], Francesca Russo[3]
[1,2,3] *University of Naples "Federico II", DICEA (Department of Civil, Architectural and Environmental Engineering), Italy*

Abstract: The structural increase of rail networks in recent years, aimed at transforming existing lines in high speed and/or high capacity lines, implies an increase of stress resulting from a more intense exercise and a more rapid evolution of the decay of rolling stock and infrastructure, highlighting noise and environmental damage caused by vibrations. In recent years, rail transport systems have often been subjected to complaints from the population living near railway lines, where the annoyance is usually caused by the emission of noise and vibrations. This problem, coupled with the growing sensitivity to the environmental impact, requires the increasing study of vibrations and sound , both for new infrastructure and for the adaptation and the upgrading of existing lines. Railway vibrations are secondary localized wave motions, due to the dynamic interaction between several complex mechanical systems: rolling stock, wheels, rails and trackbed. Such vibratory motions propagate in the ground-born, generating different dynamic effects on the receptors; these effects can disturb or damage facilities and people. The evaluation of the vibrational noise due to railway transport systems requires the analysis of the whole phenomenon: the generation, due to the interaction between the train and the way, is considered first; then the propagation phenomenon, influenced by surrounding soil, is studied. The aim of this research is to promote a predictive methodology of vibrations induced by metropolitan lines in Naples, due to rail defects; the propagation phenomenon is studied through a "hybrid" model, divided into two sub-models: the former, called "generation model", analyzes the dynamic interaction between the rolling stock and railway equipment; the second, called "propagation model", studies the propagation of vibration waves by means of the finite element method, applying the interaction forces on the superstructure. An adequate data set of experimental vibrations measurements is used to validate the proposed methodology.

Keywords: railway, vibrations, ground-born, rail defects.

1. Introduction

Starting in the 60s, noise has become a matter of great importance, because with its increase the population started to become aware of related problems. In 1996 during the European Commission Green Paper in Brussels, it was estimated that 20% of the population of Western Europe lived in areas where the ambient noise level was greater than 65 dB, and as much as 60% of the population lived in areas where the noise level was more than 55 dB (Future Noise Policy, 1996).

The main source of noise was represented by roads and railways traffic. Like noise, vibrations generated by rail traffic also cause annoyance; their modeling has become increasingly important in recent decades, mainly because it is linked to the assessment of the performance expected from the countermeasures adopted. Vibrations generated by the passage of railway vehicles are the result of several components, characterized by different properties of amplitude, frequency and phase angle. Vibrations usually occur at frequencies lower than 50 Hz, while at higher frequencies the phenomenon attenuates very quickly; in other words, vibrations are contained in a frequency range from 0 to 100 Hz, while noise occurs when the signal frequency is comprised between 30 and 2000 Hz (Esveld, 2001).

The amount of energy transmitted depends, in a significant way, on some factors such as the roughness of the wheels and the rails, or from the resonance frequencies of the suspension system of vehicles and the track support system. The soil acts as a filter, which generally attenuates the intensity of the vibrational components at all frequencies, except to their own natural frequencies of resonance, which amplifies the amplitude of vibrations themselves. Once they have reached building's foundations, the motion field is transmitted from the ground to the structure, changing is amplitude and frequency content.

Like the ground, the building may also amplify or attenuate the vibration level, according to the type of foundation, the type of material, the number of floors and the geometry of the structure (Clough and Penzien, 2003). Vibrations produced by trains typically do not cause structural problems, but they may produce significant distress to people who are located inside buildings. In fact, vibrations can produce perceptible movements of the floor or windows, shake objects on shelves or attached to the walls, or even roaring sounds. The wheels of the trains move on the rails by creating the vibrational energy that is transmitted to the outside through the support system of the rails.

2. State of art

Rail vibrations induced by the passage of the convoy are generated by three families of forces: the weight of the vehicle in motion, the inertial reaction of the vehicle under the effect of vertical undulation on a non-deformable rail and the force of inertia of the vehicle due to the movement of the rail. The first two groups of forces do not depend on the displacement of the rail and the mathematical formulation is easily expressed through a problem of forces with moving application point; the formulation of inertial forces of the vehicle, connected to rail vibration requires, however, references to the rail accelerations viewed by a mobile observer (moving with the vehicle itself). In addition, it is

[1] Corresponding author: manuela.esposito@unina.it

necessary to express the equation of equilibrium of two dynamic systems, the vehicle and the track, in correspondence of a moving contact point (Castellani, 2000). Defects of a railway line generate vertical acceleration on the unsprung masses of the vehicle passing over it. In this sense acceleration can be considered due to the rail's anomalies or geometric/structural abnormalities.

The defects attributable to the rail considered in this study are undulations with small wavelength. In order to predict the vibration level caused by the passage of a train, it is possible to resort to a mathematical or numerical model.

While in recent years numerical models based on F.E.M. (Finite Elements Method) or F.D. (Finite Differences) method has become widespread, in the past analytical methods were used, having simple models explanatory of the factors governing the phenomenon; moreover analytical models are characterized by a simple calibration based on experimental measurements; on the other hand, the use of such simplified models did not allow to consider complex geometries or all possible scenarios.

Despite the advantages in terms of complexity of the model, available software present numerical instability, involving that the convergence to stable solutions is not always guaranteed and it is difficult to calibrate a unique model, reliable for boundary conditions that are different from those in correspondence of which the measures in the field were carried out. For example, the choice of size of the mesh elements, the extension of the entire model, the damping of the ground and the number of points to be loaded depend on dynamic characteristics and speed of the train (Roma et al., 2010).

Several studies have focused on the vibrations induced by traveling loads, presenting different theories; some of them have been referred to the classical theories: continuous or discrete contact models.

(Castellani, 2000) analyzed and revised Fryba (Fryba, 1972) and Grassie (Grassie et al., 1982) theories, presenting a mathematical model that faithfully reproduces vibrations for a range of frequencies between 0 and 80 Hz.

(Lombaert and Degrande, 2001) introduced and validated an analytical model for the prediction of vibrations induced in the ground by the passage of vehicles (referring, in this study, to road loadings). It consists of a 2D model of the vehicle which calculates loads coming from the axes starting from the study of the longitudinal profile of the road, while induced vibrations are calculated referring to the Betti-Rayleigh Reciprocity Theorem. In subsequent studies they verified that the model overestimates high frequencies, affecting the prediction of vibrations generated in the ground. However, since the overestimation is gradually reduced at high frequencies and with distance from the source, authors were able to conclude that soil characteristics are to estimate the vibration level.

(Sheng et al., 2002) proposed the application of the Discrete Wavenumber Method - DWM, based on fictitious forces, implemented in a F.E.M. or a B.E.M., in order to describe the propagation of waves in the ground, the movement of the train in the tunnel and the propagation of the waves in that direction.

(Pezzoli, 6/2004) proposed an approach based on analytical models, validated through experimental and mixed (experimental and analytical) data. The author points out that the definition of a spectrum of vibrational level is closely related to several parameters, such as stiffness and energy dissipation capacity of primary suspension of the bogie, armament-vehicle interaction, operating conditions of the line, alteration of wheel-rail interface, train speed, type and the size of the infrastructure, section of the embankment, dynamic-structural characteristics of viaducts, mass and characteristics of foundations and piles, thickness of infrastructure and tunnels walls, nature and characteristics of the soil, structural characteristics of the buildings, mass of the rail, characteristics of the rail fastening systems. Each of these parameters is described using an analytical model. Experimental models are obtained by analytic interpretation of operational measures carried out during the passage of trains on specific railroad equipment and for a particular vehicle used by the transport system, complemented by dynamic load tests on the same equipment.

(Lai et al., 2005) developed a predictive technique of vibrations induced by a metropolitan tunnels and perceived in buildings. The representative function of the load induced by the train is defined with reference to two generation mechanisms: the first is the quasi-static deformation caused by the load in correspondence of the axle, the second are dynamic forces generated in correspondence of the undulations of the rail, represented by PSD.

(Cantisani et al., 2015) propose, in their F.E.M. model, the introduction of an absorbent layer placed at the ends of the solid representing the ground, in order to simulate what was historically schematized by the spring-damper assembly, concluding that the introduction of this layer allows to obtain results close to those calculated with analytical solutions, although the model is not exactly able to reproduce the vertical asymptote, which corresponds to the passage of Rayleigh waves in the point of observation.

Finally, a small number of studies in the literature focused on the analysis of the dynamic response of the coupled systems rolling stock/superstructure and superstructure/ground.

(Lei and Noda, 2002) considered track irregularities as the source of system excitation and represented them as a stationary and ergodic process, distributed as a Gaussian random variable represented recourring to the America Railway Standard PSD. Furthermore, the dynamic equation of the vehicle is described by an analytical model, by means of a system of 10 equations and 10 variables (10 degrees of freedom of the analyzed vehicle), whilst the dynamic equation of the rail is obtained through a F.E.M. The advantage of analyzing separately the vehicle and the track with iterative schemes lies in the fact that it is possible to easily solve the nonlinear problem which results from the calculus of interaction forces with the conventional formula of Hertz, thus enabling to avoid the asymmetry of the equation resulting from the coupling of dynamic systems.

(Nicolosi et al.,2012) and then (D'Apuzzo et al., 2014) proposed a model, called "hybrid model", applied to underground metros (Turin and Naples – Line 1) and that can be splitted into two sub-models, which follow the conventional phenomenological approach to the problem: a generation model which analyzes the dynamic interaction between the rolling stock and the superstructure, and a propagation model, which studies the transmission of vibrations in the ground surrounding the tunnel. In particular, the former is an analytical model which summarizes the superstructure as a Winkler beam on supports consisting of springs and dampers, while the latter has been achieved by making use of the F.E.M., given the complexity of the analytical schematization of the gallery.

3. The case study: Circumvesuviana Line of Naples

The aim of this paper is to apply the hybrid model to a section of the S. Giorgio – Volla Circumvesuviana Line of Naples, placed outside the gallery, and verify that the model reproduces also in this case the induced vibration, by comparison to experimental measurements. The Circumvesuviana railway connects about 50 municipalities around Naples and has a network of approximately 145 km. The main part of the network is realized with the continuous welded rail profile 50 UNI. The superstructure is almost entirely with ballast. It is characterized by a reduced gauge, 950 mm, less than the standard of other Italian railway networks.

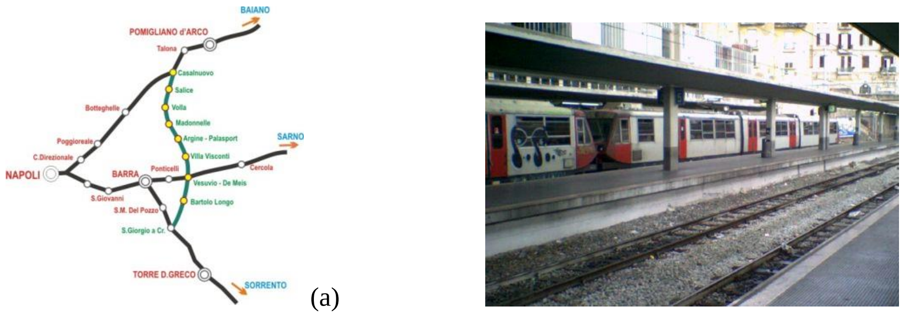


Fig. 1.
Circumvesuviana Line of Naple: Railway Network (a) and Superstructure (b)
Source: http://www.eavsrl.it/web/it

The rolling stock, ETR FE 220, is locked to the composition of three car bodies on four bogies. Each electric train is bidirectional and has two cockpits, with an overall length of 40m. Each coach is connected via a secondary suspension system to the bogies, in turn connected to the axle via a primary suspension.

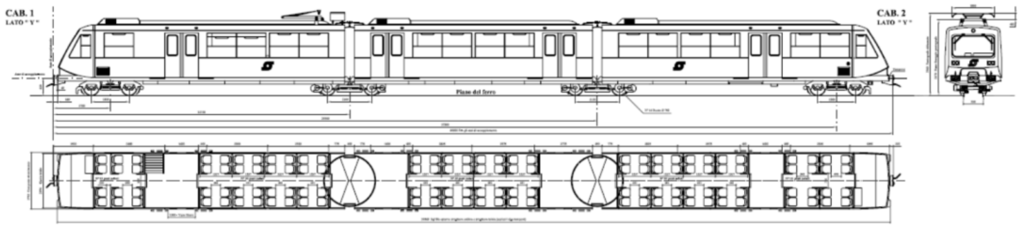


Fig. 2.
Rolling stock of the Circumvesuviana Line 1 of Naples
Source: Technical report of rolling stock

3.1. The analytical model

The analytical model, also called "generation model", reproduces the interaction between rolling stock and superstructure, by means of a set of equations governing the phenomenon. Equations describe the coupled behavior of the superstructure and the vehicle. In this study, the superstructure has been modeled as a Winkler beam resting on a continuous single layer of springs and dampers, considering 21 discrete contact points at the rail-subgrade interface.
The vehicle, in this case, is described through a discrete model made up of lumped mass and rigid bodies interconnected through springs and dampers described through mass and inertia moments of the car body, bogies and wheel axles and stiffness and damping characteristics of primary and secondary suspensions systems (Ramasco, 1993) (Esveld, 2001) (Iwnicki, 2006).The model of the Circumvesuviana rolling stock is made up of seven masses (car body, two bogies and four wheel sets), interconnected through springs coupled to dumpers. Car body and bogies have the vertical and the pitching degrees of freedom, while wheel sets, because of elastic wheels, only have the vertical degree of freedom, resulting in a 10 degrees of freedom model. The excitation of the system is represented by the irregularity of the runway, which, in absence of direct measurements, is a random phenomenon and is here represented by Frederich PSD (Forrest and Hunt, 2006):

$$S(f) = \frac{1}{v} \cdot \frac{a}{(b + {f}/{v})^3} \quad (1)$$

where:

- S(f) is the PSD of the rail defect as a function of temporal frequency, in m^2/(cycles/s),
- f is the temporal frequency of rail defects, in cycles/s,
- v is the velocity of the train, in m/s,

- a and b are “unevenness” and “waviness” respectively.

The calculus of interaction forces in the system vehicle-superstructure-ground passes through the definition of:

- interaction forces between vehicle and superstructure:

$$F_{wr} = k_H \cdot (y_w - y_P - y_r) \quad (2)$$

- interaction forces between the superstructure and the ground:

$$F_{rs} = (k_R + i \cdot \omega \cdot c_R) \cdot (y_r - y_s) \quad (3)$$

where:

- k_H it is the Hertzian stiffness of the wheel-rail interface;
- k_R, c_R are stiffness and damping characteristics of under-rail plates;
- y_W is the shift of the vehicle in correspondence of the contact with the rail in the frequencies domain;
- y_P is the track irregularity in the frequency domain;
- y_r is the displacement of the superstructure in correspondence of the contact with the vehicle in the domain of frequencies.

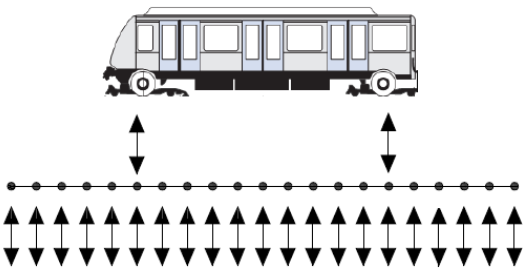


Fig. 3.
Scheme of interaction forces

Two equation sets are generated: the first is made up of 4 equations, (one for each contact point between the vehicle and the superstructure), the second consists of 21 equations, (one for each superstructure-ground contact points: the study area is 20 meters long and interaxle spacing between two consecutive under-rail plates is 1 m).

$$\begin{cases} F_{w1r} = K_H\left(\sum_{m=1}^{4} H_{w1m} \cdot F_{wmr} - Y_{p1} - H_{rw1wm} \cdot F_{wmr} - \sum_{i=1}^{n} H_{rw1si} \cdot F_{rsi}\right) \\ \vdots \\ F_{wmr} = K_H\left(\sum_{m=1}^{4} H_{wmm} \cdot F_{wmr} - Y_{p1} - H_{rwmwm} \cdot F_{wmr} - \sum_{i=1}^{n} H_{rwmsi} \cdot F_{rsi}\right) \end{cases} \quad (4)$$

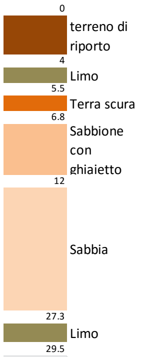
$$\begin{cases} F_{rs1} = (K_R + j \cdot \omega \cdot C_R)\left(\sum_{m=1}^{4} H_{rs1wm} \cdot F_{wmr} + \sum_{i=1}^{n} H_{rs1si} \cdot F_{rsi} - \sum_{i=1}^{n} H_{s1si} \cdot F_{rsi}\right) \\ \vdots \\ F_{rsn} = (K_R + j \cdot \omega \cdot C_R)\left(\sum_{m=1}^{4} H_{rsnwm} \cdot F_{wmr} + \sum_{i=1}^{n} H_{rsnsi} \cdot F_{rsi} - \sum_{i=1}^{n} H_{snsi} \cdot F_{rsi}\right) \end{cases} \quad (5)$$

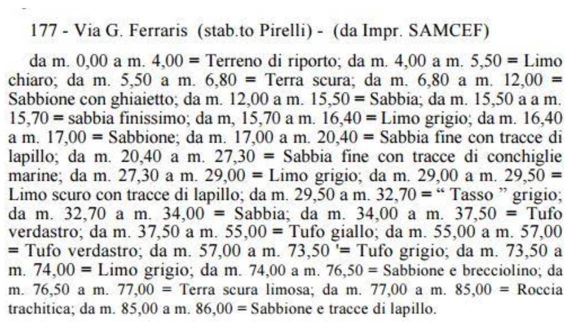
where:

- H_{w1m} is the FRF of the vertical displacement of the first vehicle wheel axle induced by a unit force applied on the *m*-vehicle wheel axle ;
- H_{rw1wm} is the FRF of the vertical displacement of the rail point under the first wheel axle induced by a unit force applied on the contact point between the *m*-wheel axle and the rail;
- F_{rsi} is the vertical interaction force in the *i*-contact point between the rail and the underling soil/structure;
- Y_{p1} is the spectrum of rail defects experienced by the first wheel axle;
- H_{rs1wm} is the FRF of the vertical displacement of the rail point located over the first contact point between the rail and the soil/structure, induced by a unit force applied on the contact point between the *m*-wheel axle and the rail;
- H_{rs1si} is the FRF of the vertical displacement of the rail point located over the first contact point connected to the soil/structure, induced by a unit force applied on the *i*-contact point between the rail and the soil/structure;
- H_{s1si} is the FRF of the vertical displacement of the soil/structure point located in the first contact point between the rail and the soil/structure, induced by a unit force applied on the soil *i*-contact point between the rail and the soil/structure.

3.2. The numerical model

The geometry of the FEM model, made using the software Lusas Alhambra S.r.l., is the result of a calibration analysis of the damping area and is based on the characteristics of the ground.
In absence of stratigraphic site test, we considered as a reference point information contained in " Il sottosuolo di Napoli " (Comune di Napoli, 1967).



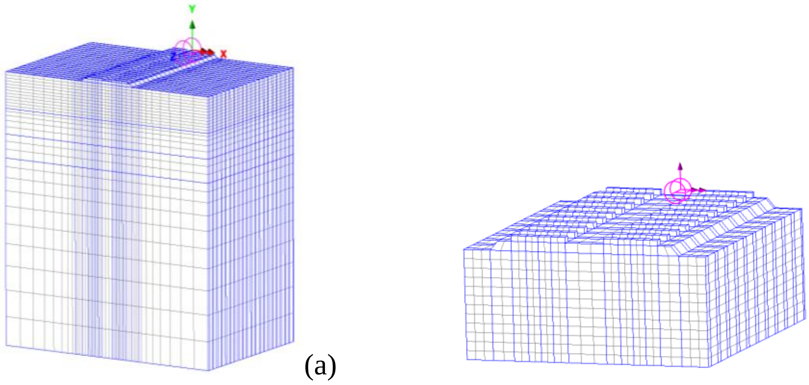


177 - Via G. Ferraris (stab.to Pirelli) - (da Impr. SAMCEF)

da m. 0,00 a m. 4,00 = Terreno di riporto; da m. 4,00 a m. 5,50 = Limo chiaro; da m. 5,50 a m. 6,80 = Terra scura; da m. 6,80 a m. 12,00 = Sabbione con ghiaietto; da m. 12,00 a m. 15,50 = Sabbia; da m. 15,50 a a m. 15,70 = sabbia finissimo; da m, 15,70 a m. 16,40 = Limo grigio; da m. 16,40 a m. 17,00 = Sabbione; da m. 17,00 a m. 20,40 = Sabbia fine con tracce di lapillo; da m. 20,40 a m. 27,30 = Sabbia fine con tracce di conchiglie marine; da m. 27,30 a m. 29,00 = Limo grigio; da m. 29,00 a m. 29,50 = Limo scuro con tracce di lapillo; da m. 29,50 a m. 32,70 = " Tasso " grigio; da m. 32,70 a m. 34,00 = Sabbia; da m. 34,00 a m. 37,50 = Tufo verdastro; da m. 37,50 a m. 55,00 = Tufo giallo; da m. 55,00 a m. 57,00 = Tufo verdastro; da m. 57,00 a m. 73,50 '= Tufo grigio; da m. 73,50 a m. 74,00 = Limo grigio; da m. 74,00 a m. 76,50 = Sabbione e brecciolino; da m. 76,50 a m. 77,00 = Terra scura limosa; da m. 77,00 a m. 85,00 = Roccia trachitica; da m. 85,00 a m. 86,00 = Sabbione e tracce di lapillo.

Fig. 4.
Stratigraphy in the vicinity of the study area

The study area is surrounded by a damping area in order to simulate the energy dissipation phenomenon due to material damping, by recurring to the Rayleigh approach. The cylindrical surface is constrained in both radial and tangential directions, while constraints are also placed on the plane of symmetry along the z-axis in order to fulfill the requirement of symmetry.Pulse vertical forces are applied on sleepers on the plane of symmetry, in order to derive the Frequency Response Functions (FRF), to be introduced in the mentioned equation sets. A static analysis allowed to verify the congruence of the model.



(a) (b)

Fig. 5.
3D FEM model developed for the propagation model: complete model(a) and study area (b)

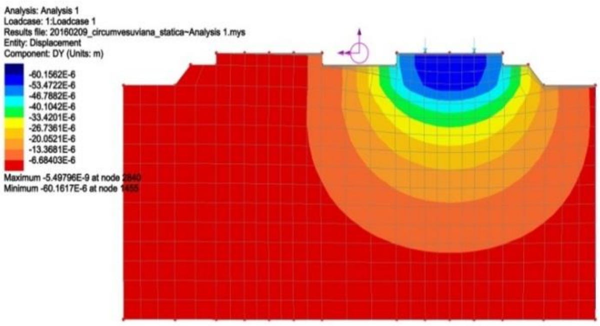
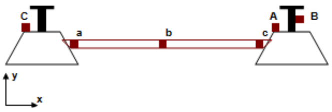


Fig. 6.
Deformed mesh (static analysis) of the propagation model

3.3. Experimental data

Through the use of accelerometers acceleration measurements in amplitude and frequency content were obtained. Three sensors were arranged in points A, B, C; in each of them an accelerometric block with two sensitivity axes oriented according to the Y axis and the X axis was installed. The sampling frequency was 1000 Hz. A section named "Section 4", located 6600,37 m far from S. Giorgio station, was chosen for the simulations.



Punto	Tipo di sensore	Asse di sensibilità
A	Accelerometro	X,Y
B	Accelerometro	X,Y
C	Accelerometro	X,Y

(a)

(b)

Fig. 7.
Scheme of accelerometers arrangement (a) and Localization of the monitoring section (b) (STRAGO, 2003)

In order to adapt the Frederich PSD (referred to the speed) to the accelerometer measurements available, the application of the integration method is needed.
Consider a single-degree-of-freedom system undergoing sinusoidal excitation. The velocity is obtained by taking the derivative, whilst the acceleration is obtained by taking the derivative of the velocity:
These relationships can be applied to the PSD functions
Let:

- DPSD = displacement power spectral density
- VPSD = velocity power spectral density
- APSD = acceleration power spectral density

where each PSD is function of the frequency f (resulting an angular frequency $\omega=2\pi f$)
Resulting relationship is:

$$APSD = \omega^4 \cdot DPSD = (2\pi f)^4 \cdot DPSD \tag{6}$$

3.4. Results

Results from the numerical simulations were finally confronted with experimental data.
The comparison, in the frequency domain, is shown in Figure 8.
For the Nyquist-Shannon theorem the maximum frequency investigated is 500 Hz, since a sampling frequency of 1000 Hz was adopted. As it can be observed in the figure, a fairly good agreement between the numerical simulation and experimental data in frequency domain was registered.
As far as the comparison in the time domain is concerned, unfortunately we were not able to do it, since the company who carried out the monitoring campaign gave us results analyzed in the frequency domain; furthermore they were subjected to an average and low-pass filter, so it was impossible to reconstruct the signal in the time domain by inverse Fourier transform.

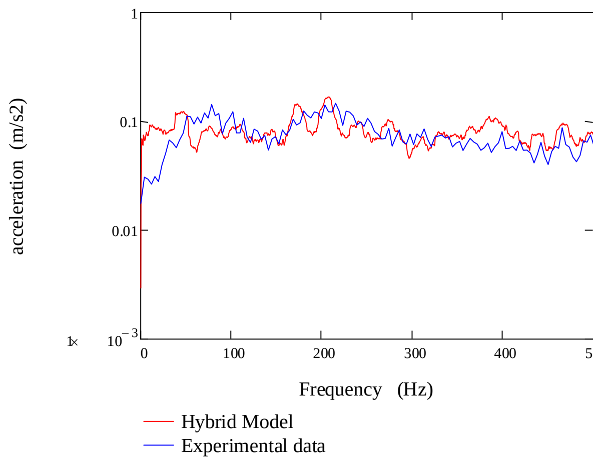


Fig. 8.
Comparison between experimental data and numerical simulations in the frequency domain

4. Conclusions

The purpose of this research was to study a predictive model of vibrations induced by the passage of railway vehicles, calibrated on the basis of the comparison between results coming from numerical simulation and a vibration monitoring campaign.

The innovation of this study, compared to other present in the literature, is that the "hybrid model” is the result of a combination of analytical and numerical models, thereby taking advantage of the simplicity and manageability of the former, as well as the versatility and adaptability to multiple scenarios of the latter.
The simulation is over, of course, through the study of the geometry of the site, the soil characteristics and the definition of analytical models to outline the superstructure of the metro lines under study, as well as the convoys.
Results demonstrate that there is a satisfactory agreement in the comparison between experimental data and numerical simulations (output of the "hybrid" model); registered variances may be attributable to mistakes made during the acquisition of the signal.
Furthermore the PSD is a useful tool for the simulation of a random phenomenon, such as the irregularity of the runway, in absence of direct measurements.

References

Cantisani, G.; Loprencipe, G.; Zoccali, P. 2015. Calibrazione di modelli FE per lo studio delle vibrazioni ferroviarie mediante misure sperimentali.
Castellani, A. 2000. Vibrations generated by rail vehicles: a mathematical model in the frequency domain, *Vehicle System Dynamics*, 153-173.
Clough, R.; Penzien, J. 2003. *Dynamics of Structures.* Berkeley: McGraw-Hill Education.
Comune di Napoli. 1967. *Il sottosuolo di Napoli.* Napoli.
D'Apuzzo, M.; Esposito, M.; Festa, B.; Nicolosi, V. 2014. Modelling vibrations induced by underground railways in urban areas. In *Proceedings of ICTTE (International Conference on Traffic and Transport Engineering)*, 496-504.
Esveld, C. 2001. *Modern Railway Track.* Delft: MRT-Productions.
Forrest, J.A.; Hunt, H.E. 2006. Ground vibration generated by trains in underground tunnels, *Journal of Sound and Vibration*, 706-736.
Fryba, L. 1972. *Vibrations of soils and structures under moving loads.* Groningen: Noordhoff International Publishing.
Grassie, S.L.; Gregory, R.W.; Harrison, D.; Johnson, K.L. 1982. The Dynamic Response of Railway Track to High Frequency Vertical Excitation, *Journal of Mechanical Engineering Science*, 77-90.
Iwnicki, S. 2006. *Handbook of Railway Vehicle Dynamics.* Boca Raton: Taylor & Francis Group.
Future Noise Policy, European Commission Green Paper, COM(96) 540 final. 1996. Brussels.
Lai, C.; Callerio, A.; Faccioli, E.; Morelli, V.; Romani, P. 2005. Prediction of railway-induced ground vibrations in tunnels, *Journal of Vibration and Acoustics*, 503-514.
Lei, X.; Noda, N.-A. 2002. Analyses of dynamic response of vehicle and track coupling system with random irregularity of track verticla profile, *Journal of Sound and vibration*, 147-165.
Lombaert, G.; Degrande, G. 2001. Experimental validation of a numerical prediction model for free field traffic induced vibrations by in situ experiments, *Soil Dynamics and Earthquake Engineering*, 485-497.
Nicolosi, V.; D'Apuzzo, M.; Bogazzi, E. 2012. A unified approach for the prediction of vibration induced by underground metro, *SIIV - 5th International Congress - Sustainability of Road Infrastructures*, 62-71.
Pezzoli, P. 6/2004. Le vibrazioni indotte dal traffico su rotaia e tecniche di previsione, *Ingegneria Ferroviaria*, 521-545.
Ramasco, R. 1993. *Dinamica delle strutture.* Napoli: CUEN.
Roma, V.; Abate, G.; Mancarella, A.; Pantaleo, M.; Pezzoli, P. 2010. Vibrazioni generate dai treni AV sulla linea Torino-Milano e sistemi di mitigazione, *Ingegenria Ferroviaria*, 427-445.
Sheng, X.; Jones, C.; Thompson, D. 2002. *Ground vibration generated by harmonic load moving in a circular tunnel in a layered ground.* Southampton.
Strago, S. 2003. *Indagini dinamiche finalizzate al confronto fra il comportamento della traversa biblocco tipo "VAX 95 I 50 NABLA" e la traversa biblocco tipo "VSB 95 I 50 NABLA".*

NEW APPROACHES OF STRATEGIC CONTROL IN RAILWAY TRANSPORT IN THE CONTEXT OF SUSTAINABLE MOBILITY AND COMPETITIVENESS

Anna Dolinayová[1], Juraj Čamaj[2], Jozef Daniš[3]
[1,2,3] University of Žilina, Faculty of Operation and Economics of Transport and Communications, Department of Railway Transport, Univerzitna 8215/1, 010 26 Žilina, Slovakia

Abstract: Company strategy cannot be created without the realization of detailed analysis of the company surroundings (external analysis) and the company itself (internal analysis). Strategic analysis of the company surroundings is a process to monitor and evaluate competition, so that the company can eliminate or reduce threats on the one hand and make use of opportunities on the other. Strategic internal analysis is aimed at the strengths and weaknesses of the company. Identification of these factors makes it possible to create strategy with respect to existing or future enterprise production factors. This article deals with new approaches to assist of company management by controlling the strategic analysis phase. It is the result of theoretical and methodological research for the realization of strategic analysis of railway companies with respect to transport market specifics, and the possibilities to increase railway transport competitiveness. Based on this, we designed and validated methods suitable to improve upon relevant strategic analysis. These methods were validated using model situations.

Keywords: competitiveness, methods of strategic analysis, monitoring, railway transport, strategic controlling.

1. Introduction

The basic objective of strategy management is to estimate future trends and to formulate strategy tasks so that the company will have a competitive advantage of a longtime existence on the market. This role can be achieved on the basis of synthesis of available information and knowledge about the company and their environment. Strategy controlling should fulfil mainly informational, analytic and coordinate roles during the analysis, creation and implementation phases. The analysis phase should afford the all relevant information about the past development of internal and external business indicators and their assumed development. Controllers must know and applicate appropriate methods for realization this analysis. In rail companies, the application of general methods and techniques of strategy analysis requires not only their adaptation to concrete conditions but often transformation of the methods and techniques to match the specific needs of railway transport.
Nowadays, strategy management theory is developed by two separate schools:

- Ansoff prefers target orientation of strategic development; while
- Mintzberg deals with process-oriented strategic development.

Ansoff developed the method of strategic analysis 27 years ago Ansoff (1979). He dealt with the issue of adapting corporate strategy around business and their changes in the works “The New Corporate Strategy” (Ansoff, 1998) and “Optimizing profitability in turbulent environments. A formula for strategic success” (Ansoff, 1993). Porter has been concerned with the issue of competitive strategy and its patterns of the industrial structure and value chain since 1980 (Porter, 1980). Recently, Porter has dealt with the impact of intelligent products to change competitiveness in companies (Porter and Heppelmann, 2014; Porter and Heppelmann, 2015).
Presently, when the environment of companies is not predictable, it is not possible to create strategy with explicit targets. Companies need flexible strategies that for changing conditions (Mintzberg, 1987). Mintzberg criticized the traditional concept of strategy planning and defined five basic strategies (Mintzberg's five Ps of Strategy): Plan, Ploy, Pattern, Position, Perspective (Mintzberg, 1994).
The liberalization of the rail transport market entails increases in competitiveness for companies that provide the services for passengers or freight rail transport. Therefore, companies must differentiate their business activities so as to be successful in a competitive market. Such differentiation in combination with a rapid response to changes in the business environment and adaptation to the requirements of customers increases the demands on management, which must include the amount of information from external and internal environments of the company.
Controlling becomes one of the most important areas of support in business management. In railway undertakings, the existence of an effective system of controlling a necessary condition for business success with respect to specific business activities is often carried out internationally. In the area of strategic controlling, problems in the application of generally applicable methods arise for the conditions of rail transport. The solution to this problem is to design generally applicable methods of strategic analysis on the conditions of companies providing rail transport services.

2. Material and methods

The creation of strategy must be based on a thorough strategic analysis of corporate surroundings and the company itself. Currently, there are many methods and techniques that are more or less suitable for the realization of strategic analysis on companies providing services in the railway sector.

[1] Corresponding author: anna.dolinayova@fpedas.uniza.sk

2.1. Methods of strategy analysis

Strategy analysis is the fundamental part of strategy controlling. While strategy managers create and implement new strategies in companies, the strategic role of the controller is provided with the necessary information to create strategy, i.e. to realize strategic analysis.
Strategy analysis is performed in two basic areas:
- Analysis of the company's environment; and
- Analysis of the company.

Analysis of the company's environment can by realized by:
- PEST analysis, and
- Porter's five forces analysis.

PEST analysis or extended version (PESTLE analysis) deals with analysis of the global company environment. Aguilar is considered to be its founder. In 1967, he published the work "Scanning the Business Environment," in which the determined four basic sectors affecting companies: Economical, Technical, Political, and Social. PESTLE analysis is expanded to include Legal and Environmental. Currently, it is used not only for strategy analysis of company environment, but also for the evaluation of the business environment of countries (Palova, 2014).
Porter's five forces model deals with the competitive environment of companies (i.e. sector competition). These forces include (Porter, 2008):
- Threat of new entrants;
- Threat of substitutes;
- Bargaining power of buyers;
- Bargaining power of suppliers; and
- Industry rivalry.

Strategy analysis should provide a comprehensive overview of the internal environment of the company: its aim is to identify the key skills and competencies of the company. The most commonly used methods of strategic analysis of the company include (Eschenbach, 2000):
- Potential Analysis;
- Strategic Balance;
- Analysis of the value chain and cost structure; and
- Strategy Business Unit (SBU) analysis.

Potential analysis focuses on the existing potential success of the company and the strategic resources of the company. First, it analyzes the strengths and weaknesses, and then draws up a list of successes and failures and their causes in individual areas of the company (such as production, logistics, sales, human resources, etc.). It must be developed to quantify the reasons for the successes and failures.
Strategic Balance involves the company's dependence on different stakeholders. Mann dealt this problem for the first time. He proposed five major corporate functions and corporate resources to build strategic balance – capital, staff, material, sale and know-how (Mann, 1989).
Company dependence on individual interest groups is almost always passive (enterprise depends on stakeholders) but can also be active (stakeholders are dependent on the company). After establishing a list of active and passive dependence, points are assigned to each interest group. Determining point scale and the actual allocation of points to the different stakeholders is subjective in nature. Strategic balance shows free space for company dealing. A sufficiently large space is considered if the sum of points of strategic balance is greater than half the maximum possible number of points.
Analysis of the value chain and cost structure of the company is used to assess the overall performance of the business process creation. The aim of this analysis is to optimize the value chain (Ghemawat, 2002). In this analysis, it is necessary to distinguish between primary and secondary activities. Primary activities are the main activities of the company, which contribute most to the profit (e.g. product production), whereas secondary activities are most often used to support the primary activities (e.g. logistics, controlling, enterprise administration, etc.).
SBU analysis deals with the product portfolio of the company. A strategic business unit is a unit or activity of the enterprise (e.g. specific product or service) that can be monitored and evaluated in isolation in terms of kind and value indicators, as well as in terms of the external environment of the company. Presently, the BCG Matrix, a newer version of the GE / McKinsey Matrix, is used in the analysis of strategic business areas.
The BCG Matrix is a portfolio model developed by the Boston Consulting Group. The BCG matrix is a simple way of plotting the firm's different business portfolios onto the same matrix, providing some guidance as to how the company's resources should be allocated across the different business units. The BCG matrix considers two elements to form its four quadrants: Growth rate of the market, and Relative market share. The growth rate of the market dimension is used as a proxy measure of the attractiveness of the market, with high-growth markets being seen as more attractive and offering more potential and opportunity. Relative market share is used as a surrogate of competitive strength. The larger the firm's market share relative to its largest competitor, the stronger the firm is in the marketplace (Fripp, 2015).
The GE/McKinsey Matrix was originally developed by McKinsey & Co. consultants in order to help the American conglomerate General Electric manage its portfolio of business units. The nine-box matrix plots the BUs on its nine cells that indicate whether the company should invest in a product, harvest/divest it, or perform further research on the

product and invest in it if there are still some resources left. The BUs are evaluated on two axes: industry attractiveness and the competitive strength of a unit. Industry attractiveness consists of many factors that collectively determine the competition level in it. There is no definite list of which factors should be included to determine industry attractiveness, but the following are the most common (McKinsey & Co., 2008):

- Long run growth rate
- Industry size
- Industry profitability: entry barriers, exit barriers, supplier power, buyer power, threat of substitutes and available complements (use Porter's Five Forces analysis to determine this)
- Industry structure (use the Structure-Conduct-Performance framework to determine this)
- Product life cycle changes
- Changes in demand
- Trend of prices
- Macro-environment factors (use PEST or PESTLE for this)
- Seasonality
- Availability of labor
- Market segmentation.

Along the x-axis, the matrix measures how strong, in terms of competition, a particular business unit is against its rivals. In other words, managers try to determine whether a business unit has a sustainable competitive advantage (or at least a temporary competitive advantage) or not. If the company has a sustainable competitive advantage, the next question is: "For how long it will be sustained?" The following factors determine the competitive strength of a business unit (Jerevicijus, 2014):

- Total market share
- Market share growth compared to rivals
- Brand strength (use brand value for this)
- Profitability of the company
- Customer loyalty
- VRIO resources or capabilities
- Business unit strength in meeting industry's critical success factors
- Strength of a value chain
- Level of product differentiation
- Production flexibility.

2.2. Application and transformation methods on the conditions of rail companies in the Slovak Republic

In rail companies, strategic analysis can be carried out using the methods that were described in the precious section, but these methods must be adjusted to railway transport conditions. The process of realization of strategy analysis consists of analyzing companies' environment and strategy analysis of the company, exactly the same as in any other sector.

2.2.1. PESTLE analysis

It is very important to realize the analysis of the global environment in the individual area. PESTLE analysis can be reduced to PEST analysis in view of the fact that the environmental area is a part of transport policy. In the individual part of PESTL analysis, important factors can be identified that affect rail companies.

Political factors. It is needed to analyze mainly European and national transport policy in the rail transport area. European transport policy is embedded in the document "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system" about the future of European transport by 2050. In this document, initiatives are designated to realize the vision of a competitive and sustainable transport system. From the basic vision, priorities and objectives of the strategy defined in rail transport in the European transport policy, it is also based on national transport policy: "Strategy of development of transport SR by the year 2020".

Global objectives are developed into specific objectives and priorities, along with measurable indicators. As part of strategic controlling, analyzing transport policy provides information on planned activities in the field of railway transport, which in future may not only affect competition in the rail transport market, but also in the transport market as a whole.

Economic factors. The basic areas that must be analyzed include economic growth pursued through macroeconomic aggregates, such as gross domestic product (GDP), gross national product, personal disposable income, output, etc. The relationship between the volume of freight and GDP across the EU varies. The index of total freight to GDP index was, in the period 2000–2010, according to Eurostat, in Slovenia + 66% in Germany, + 1% in the Czech Republic 14%, in Poland + 34% and -14% in Slovakia.

Equally disproportionate is the development between different transport modes. The development of passenger transport is significantly influenced by the living standards of the population and the quality of public mass passenger transport. If they are not provided with quality services at reasonable prices, there will be a decline of rail passenger transport (as well as bus services), and an increase in personal car use.

Socio-culture factors. These factors mainly affect the development of passenger rail transport and can be classified as follows (Hornak et al., 2015):

- Demographics (e.g. age structure of population, households, aging index)
- Labor mobility (the effect of increasing the distance of commuting to / from work)
- Lifestyle changes (e.g. the relationship between work and leisure time, use of leisure time)
- Regional disparities (time effect uniformity in passenger traffic at the end and beginning of the week)
- Migration (creating social ties with the migrants' countries of origin increases demand for passenger transport) etc.

Technical and technological factors determine the level of travel and the use of rail freight. These factors include the development of new vehicles, the state of transport infrastructure (the construction of motorways, modernization of railway infrastructure), implementation of the technical specifications for interoperability and construction of intermodal terminals, changes in information technology, and the existence of intelligent transport systems.

Legal. The basic legislative conditions for railway construction, operation of railway infrastructure, operation of transport on railway infrastructure, as well as the rights and obligations of the natural and legal entities related to these activities are stipulated by the Act on railways and its implementing decree (Network Statement ZSR, 2015):

- Act of the National Council of the Slovak Republic No 513/2009 Coll. on Railways and on amendment and completion of certain acts as amended by later regulations (hereafter called the "Act on Railways")
- Act of the National Council of the Slovak Republic No 514/2009 Coll. on Railway Transportation as amended by later regulations (hereafter the "Act on Railway Transportation")
- Act of the National Council of the Slovak Republic No 258/1993 Coll. on the ŽSR as amended by later regulations
- Decree of the Ministry of Transport, Posts and Telecommunications of the Slovak Republic No. 351/2010 on Railways Traffic Order as amended by later regulations
- Decree of the Ministry of Transport, Posts and Telecommunications No.205/2010 Coll. on Determined Technical Appliances and Determined Activities and Activities on Determined Technical Appliances
- Decree of the Railway Regulatory Authority No. 3/2010 of 2 December 2010, setting the charges for the access to railway infrastructure
- Decree of the Ministry of Transport, Posts and Telecommunications No.245/2010 Coll. on expert competences, physical and mental competences of persons in railway operations and transport on railway as amended by later regulations
- Decree of the Railway Regulatory Authority No. 2/2010 of 18 August 2010 on the regulatory framework for laying down charges for the access to railway infrastructure
- Decree of the Railway Regulatory Authority No. 7/2012 of 24 May 2012; by which the Decree of the Railway Regulatory Authority No. 3/2010 of 2 December 2010 setting the charges for the access to railway infrastructure is being amended.

2.2.2. Porter's five forces analysis

The analysis of the competitive environment should be initially focused on the overall transport market, where the main competitors are road freight and individual motoring. In the freight market, not only should the main competitors and freight traffic volume be analyzed,, but also a comparative analysis should be carried out of the development of legislative, economic and transport performance of road freight transport. In passenger transport, households should be analyzed (e.g. the method category of households), as well as the quality requirements of passengers on public mass passenger transport. Then we can proceed to analyze the various forces affecting the competitive environment in the context of rail transport.

Competition in the sector. Competition in the rail transport market began with European rail reform, which consisted initially of the vertical separation of the infrastructure manager and the operation of train services, and later with the horizontal separation of rail passenger and freight traffic, allowing entry of competing carriers (Tomes et al., 2016). In the Slovak Republic, the rail freight market was fully liberalized on 1 January 2007; the market for international rail passenger services has been fully open since 1 January 2010; national markets for rail passenger services in some European countries are still closed.

In Slovakia, there has been an increased number of private railway companies that are licensed to operate a service on track since the liberalization of the rail transport market. Currently, more than 40 companies are licensed, but not all provide rail services. Their share of the rail transport market has varied. The largest share of freight transport is ZSSK CARGO, corp. and for passenger transport Železničná Spoločnosť Slovensko, founded and wholly owned by the Slovak Republic. The rights of the State as a shareholder by the Ministry of Transport, Construction and Regional Development Infrastructure manager – Železnice Slovenskej republiky has a specific position: it is a natural monopoly.

Potential new competitors may be newly created companies or companies that are currently implementing a different mode of transport. In the past, a major barrier to the entry of new competition on the market was high capital intensity (i.e. the purchase of rolling stock, and high fees for licensing). Currently, established companies have a business advantage over new ones, especially in the field of training (e.g. know-how of managers, as well as operational staff), participation in international railway institutions and organizations, in building a network of information and customer centers, and in the use of information systems, with certain modules directly linked to information systems and infrastructure managers.

Suppliers. The rail market is specific in suppliers. The main supplier for companies providing transport services is the infrastructure manager. The infrastructure manager is responsible for the quality and safe infrastructure, affecting the quality of rail service operators (Kendra et al., 2012). The technical - technological part of the railway infrastructure must also be analyzed, as well as current and future charges for its use. Prices for access to the railway infrastructure in Slovakia are regulated and are determined by Decree No.2/2010 Office for railway transport regulation.

Customers. In the rail freight market, customers have a great bargaining position, because it is most often the companies that buy transport service operators on a large scale. At present, a number of railway companies is dependent on a few customers. In passenger transport there is the main customer state that orders transport performance on the basis of the contract of transport services in the public interest. The exceptions are the commercial trains of other operators of passenger transport.

Substitutes. A substitute is defined as: "a product or service that can replace the original product or service because they satisfy similar needs. Usually comes from a different industry than the original" (Slávik, 2005). Considering this definition, there are no substitutes in the transport market. In the event that we will be guided only by the railway market, rail freight services are the most commonly substituted by road and inland waterways; in the case of rail passenger transport, the principal substitutes are cars and airplanes.

The task of controlling is to obtain available information from the company environment, to compile reports on the development of the most important indicators, and to try to anticipate developments that could severely affect the railway undertaking.

2.2.3. Potential analysis

There must be a careful analysis of the various functional areas of the rail company at the beginning of the potential analysis; in particular management, operation, rail vehicles, energetics, business and services, finance and accounting, logistics, personal sources and information systems (Cerna and Masek, 2015). A list of successes, failures and their reasons in these areas can be compiled. There is a need to differentiate between internal and external causes. Figure 1 shows an example of this analysis for the conditions of rail companies.

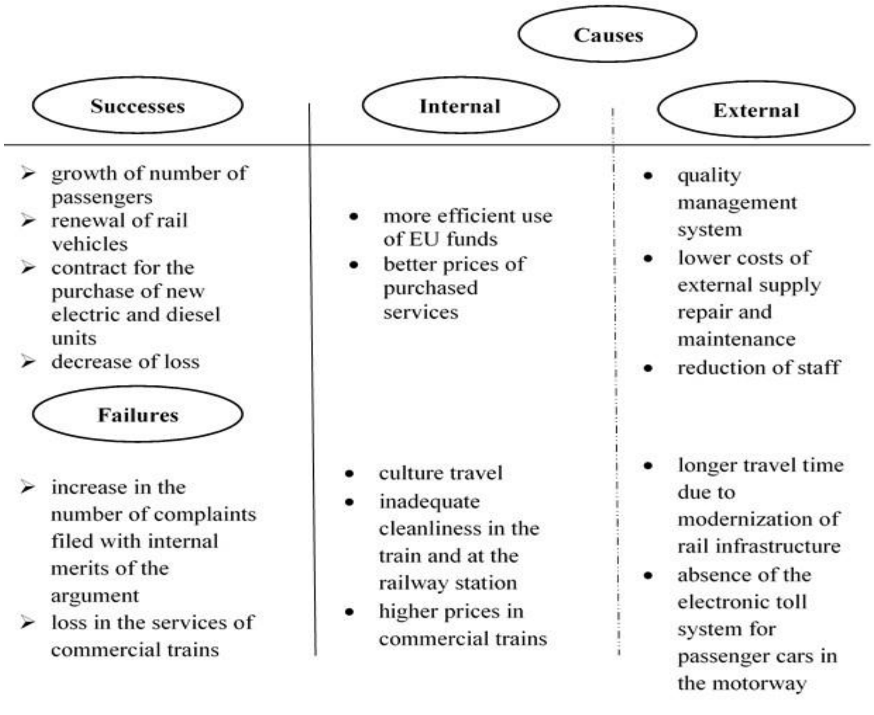


Fig. 1.
Examples of potential analysis in a rail company
Source: Authors

For success, the railway companies must follow a critical approach to their analysis and to avoid subjective evaluation. A good tool is the use of data from management information systems and the empirical results from market research.

2.2.4. Strategic Balance

Strategic balance should provide a comprehensive image of the dependence of a company for different stakeholders. Railway companies should study the dependence of stakeholders on Owner (investor), Staffs, Costumers, Suppliers and The state. Table 1 gives examples of active and passive dependence on the individual stakeholders for rail transport.

Table 1
Strategic balance in rail transport

Stakeholder	Active dependence	Passive dependence
Owner (Investor)	▪ main source of income for the owner ▪ goodwill of company ▪ possibility of obtaining funds from EU	▪ dependency on state funding (subsidies) ▪ difficulties in obtaining commercial loans
Staff	▪ low staff turnover ▪ adequate level of wages compared to the average national wage ▪ possibility of career growth	▪ high specialization ▪ lack of qualified workers for certain jobs
Costumers	▪ natural monopoly (infrastructure manager) ▪ meeting delivery times ▪ supply of additional services ▪ ownership of modern means of transport ▪ supply of other services in the train	▪ a few major customers ▪ no direct customer contact ▪ financial problems of major customers ▪ strong connection to customer logistics processes
Suppliers	▪ one of the main customer suppliers ▪ possibility of leasing vehicles ▪ regulated charges for the use of railway infrastructure	▪ sole supplier (infrastructure manager) ▪ problems with interoperability in international railway transport
State	▪ high number of employees ▪ obligations of the state to ensure conditions for sustainable mobility ▪ transport serviceability	▪ necessary infrastructure ▪ modernization of railway infrastructure ▪ legal framework conditions ▪ number of qualified graduates from secondary schools and universities

Source: Authors

Points are assigned to each interest group by establishing a list of active and passive dependencies; identifying the points scale and the actual allocation of points to the different stakeholders is subjective in nature. The point scale is most often chosen from 0–10, or a percentage from 0–100%. The higher the dependence on the interest group, the higher the point evaluation. It is necessary to use the difference between the maximum potential and the actual value in counting the points of passive dependency.
Strategic balance shows a free area for company meetings. Sufficient scope for negotiation occurs when the sum of points of strategic balance is greater than half the maximum possible number of points. In the case of a high number of points, it is important to focus on strategic bottlenecks, i.e. those stakeholders that have high passive dependence.

2.2.5. Strategy Business Unit analysis

In rail companies it is appropriate to use GE/McKinsey Matrix methods for the realization of Strategy Business Unit analysis. Market attractiveness can be quantified by the following factors:

- Transport market size/ Rail transport market size
- Market growth rate
- Profitability
- Price stability
- Stability of sale
- Capital intensity
- Bargaining position of suppliers and costumers
- Competition
- Legal framework
- Technology.

The following factors determine the competitive advantages of a business unit in railway transport:

- Share of the transport market/rail transport market
- Development of share in the transport market
- Delivery times
- Safety
- Information about deliveries

- Additional services
- Unit value (€ per net tonne kilometer)
- Costs per gross/net tonne kilometer
- Level of marketing.

The possibilities of factor evaluation are described in Section 2.1. In view of the fact that evaluation is subjective, it should be realized by a greater number of controllers, in order to decrease the risk of a higher number of points when they are inadequate.

3. Results

The single use of methods of general strategy analysis is not possible in rail companies. Moreover, it is important to evaluate factors correctly in the individual methods. Inadequate application and evaluation can cause the formation of incorrect strategy, leading to unused potential in the company, and possibly even its eventual disappearance. The GE/McKinsey Matrix was validated on a model example. Tables 2 and 3 show the evaluation results for companies providing services in rail freight transport.

Table 2
Evaluation of market attractiveness of strategy business unit in rail freight transport

Factor	Commodity A			Commodity B		
	Weight of factor [%]	Evaluation of attractiveness [%]	Total evaluation [%]	Weight of factor [%]	Evaluation of attractiveness [%]	Total evaluation [%]
Transport market size	10	39	3.90	16	74	11.84
Market growth rate	3	45	1.35	9	62	5.58
Profitability	12	63	7.56	8	49	3.92
Price stability	4	28	1.12	3	39	1.17
Stability of sale	6	42	2.52	5	24	1.20
Capital intensity	13	33	4.29	9	82	7.38
Bargaining position of suppliers	16	29	4.64	12	73	8.76
Bargaining position of costumers	7	21	1.47	11	58	6.38
Competition	5	36	1.80	13	52	6.76
Legal framework	11	42	4.62	6	89	5.34
Technology	13	58	7.54	8	92	7.36
Total	100	x	**43.81**	100	x	**65.69**

Source: Authors

We realized this evaluation for two commodities. Commodity A represented goods traffic under specific conditions, while commodity B represented traffic of a classical wagon consignment in a through train.

Table 3
Evaluation of competitive advantages of strategy business unit in rail freight transport

Factor	Commodity A			Commodity B		
	Weight of factor [%]	Evaluation of performance [%]	Total evaluation [%]	Weight of factor [%]	Evaluation of performance [%]	Total evaluation [%]
Share on the transport market	7	36	2.52	13	33	4.29
Development of share on transport the market	4	51	2.04	12	54	6.48
Delivery times	17	77	13.09	11	42	4.62
Safety	24	93	22.32	6	75	4.50
Information about deliveries	13	89	11.57	7	90	6.30
Additional services	18	62	11.16	5	61	3.05
Unit value (€ per net tonne kilometer)	9	72	6.48	18	49	8.82
Costs per gross/net tonne kilometer	3	56	1.68	15	64	9.60
Level of marketing	5	36	1.80	13	53	6.89
Total	100	x	**72.66**	100	x	**54.55**

Source: Authors

The application of the GE/McKinsey Matrix showed that commodity A was in the green field, which it means that it is an advantageous position, and that the company should continue to develop this strategic business unit. Commodity B

was in the yellow field, where the company must decide if it keeps developing this strategic business unit. In view of the fact that the evaluation of the market attractiveness of commodity B was higher (Table 2), it should be possible to realize the investment strategy with a view towards increasing income of condition transport market growth.
The results showed that the evaluation must be realized precisely and preferably objectively (although the weight of factors is determined by a team of company controllers or managers). If the weight of the factors “profitability” and “technology” were changed for commodity A (other conditions: *ceteris paribus*), this commodity would turn from the green to the yellow field of the GE/McKinsey Matrix.

4. Conclusions

Strategic business management is the fundamental element to successful businesses in the global economy. The basic task of strategic management is to estimate future trends and to formulate strategic aims based on the synthesis of available information and knowledge about the business, in order to achieve competitive advantages and long-term prosperity. Strategic controlling should perform many tasks, mainly informational, analytical and coordination in the control, creation and implementation phases. The strategic controlling role is increasing continually in today’s global and rapidly changing economic and social conditions. The activity of controlling is very important in railway transport, which is characterized by specific conditions for providing rail services. It is very important that the controllers in rail companies know the methods for realizing relevant strategy analysis in detail. The methods proposed here are effective tools for the implementation of strategic analysis, allowing the managers to develop good strategies. Those railway companies with a well-developed strategy can provide rail services on the transport market in the long term, therefore increasing the competitiveness of rail transport, and reducing the environmental burden.

Acknowledgments

This paper was supported by the VEGA Agency, Grant No. 1/0701/14 “The impact of railway freight transport market liberalization on social transport costs” and VEGA Agency Grant No. 1/0095/16 "Assessment of the quality of connections on the transport network as a tool to enhance the competitiveness of public passenger transport system", at the Faculty of Operations and Economics of Transport and Communication, University of Žilina, Slovakia.

References

Ansoff, H.I. 1979. *Strategic Management*. New York: John Wiley & Sons, Inc. USA. 242 p.
Ansoff, H.I.; McDonnell, E.J. 1988. *The New Corporate Strategy*, New York: Wiley, Inc. USA. 258 p.
Ansoff, H.I.; Sullivan, P.A. 1993. Optimizing profitability in turbulent environments. A formula for strategic success, *Long Range Planning*, 5(26): 11-23.
Cerna, L.; Masek, J. 2015. The Proposal the Methodology of the Supply Chain Management in Transport and Logistic Company. In *Proceedings of the 19th International Scientific Conference on Transport Means*, 567-570.
Hornak, M.; Struhar, P.; Psenka, T. 2015. Evaluation of high-standard public transport centres in the Slovak Republic, *Bulletin of Geography-Socio-Economic Series*, 30(30): 59-70.
Eschenbach, R. et al. 2000. *Controlling*. Stuttgart: Schäffer-Poeschel Verlag. 812 p.
Fripp, G. 2015. BCG Matrix and the Experience Curve. Guide to the BCG Matrix. Available from Internet: <http://www.thebcgmatrix.com/bcg-matrix-theory/bcg-matrix-overview/>.
Ghemawat, P. 2002. Competition and business strategy in historical perspective, *Business History Review*, 1(76): 37-74.
Jurevicius, O. 2014. GE McKinsey Matrix. Available from Internet: <https://www.strategicmanagementinsight.com/tools/ge-mckinsey-matrix.html>.
Kendra, M.; Babin, M.; Barta, D. 2012. Changes of the infrastructure and operation parameters of a railway line and their impact to the track capacity and the volume of transported goods. In *Proceedings of the Transport Research Arena 2012. Procedia Social and Behavioral Sciences*, 743-752.
Mann, R. 1989. *Praxis strategisches Controlling mit Checklist und Arbeitsformuralen*. München: Verlag. 229 p.
McKinsey & Co. 2008. Enduring Ideas: The GE–McKinsey nine-box matrix. Available from Internet: <http://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/enduring-ideas-the-ge-and-mckinsey-nine-box-matrix>.
Mintzberg, H. 1987. Crafting Strategy, *Harvard Business Review*, (65): 66-75.
Mintzberg, H. 1994. *The Rise and Fall of Strategic Planning*. New York, NY. Inc. USA The Free Press, 288 p.
Network Statement ZSR. 2015, Available from Internet: <http://www.zsr.sk/anglicky/railwaysinfrastructure/marketing/network-statement.html?page_id=1047>.
Palova, Z. 2014. Analysis of Business Environment of the Czech Republic. In *Proceedings of the 15th International Scientific Conference on International Relations - Contemporary Issues of World Economics and Politics,* 413-420.
Porter, M.E. 1980 *Competitive Strategy*, Free Press, New York, Inc. USA. 396 p.
Porter, M.E. 2008. The Five Competitive Forces That Shape Strategy, *Harvard Business Review*, 1(86): 78-93.
Porter, M.E.; Heppelmann, J.E. 2014. How Smart, Connected Products are Transforming Competition, *Harvard Business Review*, (92): 65-88.

Porter, M.E.; Heppelmann, J.E. 2015. How Smart, Connected Products are Transforming Companies, *Harvard Business Review*, (93): 97-114.

Slávik, Š. 2005. *Strategický manažment (Strategy management)*. SPRINT Bratislava. SR. 403 p.

Tomes, Z.; Kvizda, M.; Jandova, M. et al. 2016. Open access passenger rail competition in the Czech Republic, *Transport Policy*, 47: 203-211.

APPLICATION OF NDT TO RAILWAY TRACK INSPECTION

Cafiso Salvatore[1], Capace Brunella[2], D'Agostino Carmelo[3], Delfino Emanuele[4], Di Graziano Alessandro[5]

[1,2,3,4,5] *University of Catania, Department of Civil Engineering & Architecture, via Santa Sofia, 64, 95125 Catania, Italy*

Abstract: Track failures are one of the main problems that railroads have faced since the earliest days is the prevention of service. The lack of a systematic monitoring brings to the impossibility to produce an effective long term railway track management system, by allocating budget where emergencies come. Latest technology can improve the rail inspection with higher cost of the equipment. The great advantage is related to the speed and precision of the measurement, avoiding to interfere with the normal use of the infrastructure. Despite that, in local railway with reduced gauge, the use of traditional monitoring systems at high speed is not feasible. In this framework the monitoring of the track with alternative non-destructive techniques (NDT), such as GPR and LWD are promising for ballast and track stiffness inspections. In recent decades, these devices have already proven their effectiveness in the field of road pavement engineering and prospects are the same in the rail sector which is increasingly growing. This paper details, with a trial on a site of investigation, the opportune and effective use of the equipment and their performance. As future work the use of NDTs is expected to affectively contribute to a creation of a reliable monitoring system for preventive maintenance strategies of railway asset and Quality Control of track works, as well.

Keywords: NDT, ground penetrating radar, light weight deflectometer, rail track, ballast.

1. Introduction

Railway lines are investments with very long life. Today many tracks are over 100 years old. Of course components and mainly rolling stock have been exchanged during the years, but parts of the track might remain the same – especially the track structure and formation. Typical lifetimes of for rails are 30 – 60 years and turnouts 20 – 30 years (H. Sundquist, Byggande, 2000). There is a clear trend towards higher speeds and higher capacity (more trains on the tracks and heavier trains). Nowadays more trains occupy the track and the competition with other means of transportation becomes harder. To face the new circumstances, more effort has to be put on track maintenance and construction QC&QA to ensure the issues of safety, comfort, serviceability and economy. Moreover, there is also a trend towards decreased time for maintenance and decreased funds for maintenance.

This could be done with the help of measurements of important parameters which are analyzed to give knowledge about the condition of the track and, with increased traffic and more frequent failures on railroads, rail inspection is more important today than it has ever been (C. NDT, 2013). Although the focus of the inspection seems like a fairly well-defined piece of steel, the testing variables present are significant and make the inspection process challenging. To keep railroads safe and prevent any high maintenance costs caused by failures on the railroads, scheduled inspections must be performed on rail tracks and soil.

Soil inspection investigates the Ballast, Subgrade, and Roadway (BSR) component, which includes all earthen materials on the track structure, tracks, and embankments (Uzarski et al., 1993). It focuses on the thickness of the ballast, subsoil material and geotechnical properties of subgrade. Traditionally, the inspection is executed mainly by digging trenches at evenly spaced intervals and in locations of special interest (Hugenschmid, 1999). Soil inspection also investigates the plants on the railroads (Eriksen et al. (2004). Latest technology can improve the rail inspection with higher cost of the equipment (Cerniglia et al., 2006). Those technologies are mainly developed directly from the railway Agency to monitor their network. The great advantage is related to the speed and precision of the measurement, avoiding to interfere with the normal use of the infrastructure.

Generally local railways have not the most advanced equipment to survey the network as well as the economic possibility for a systematic global survey. The result is that the maintenance is carried out to avoid track failures with visual and manual inspection of the track based on the experience of the technicians. Unfortunately, the lack of a systematic control and the economic difficulties, especially in local railway track lead to the impossibility of producing a long-term effective track management system. In this framework, in order to carry out soil and track inspections, for reliable preventive maintenance strategies and QC of construction works, literatures studies and practical applications conducted with Ground Penetrating Radar (GPR) and Light Weight Deflectometer (LWD) are promising for a success fully non-destructive tests.

This paper details with a trial on a site the use of GPR and LWD and their performance.

2. Ground Penetrating Radar (GPR)

The ground penetrating radar is a geophysical radar system with antennas and receivers used to perform non-destructive investigations of under-ground characteristics with high resolution and in depth (up to 3.2 m from the surface).

GPR operation principle is based on electromagnetic theory, its functioning consists in sending short electromagnetic pulses into a medium and when pulses achieve an interface they are reflected back partially and collected by the receiving antenna. The reflected energy is displayed in wave-forms and the greatest amplitudes represent the interfaces

[1] Corresponding author: dcafiso@dica.unict.it

between layers with distinct dielectric characteristics (Daniels, 2004). Ultimately, GPR measures the travel time between the transmission of the energy pulses and its reception. The collected data are processed and saved on a control unit, that is also used to generate the necessary pulses for the operation of the antennas.
The track substructure, consisting of the ballast, sub ballast, and subgrade layers, has a profound influence on track performance. The substructure performance is significantly affected by moisture accumulation and thickness of the roadbed layers (Selig & Waters, 1994). Accurate knowledge of the substructure condition is important in effectively assessing the potential for service interruptions and the need for slow orders.
In this field, the GPR seems to be a good alternative to traditional core inspection techniques. Methods of applying GPR to railways are being developed to provide a continuous evaluation of the track substructure conditions relative to subsurface layering, material type, moisture content and density.
As mentioned GPR can provide a fast, nondestructive measurement technique for evaluating railway track substructure condition (Olhoeft & Selig, 2002; Selig et al. 2003).
Main application of GPR in railway track are:

- Monitoring the condition of railway ballast, and detect zones of clay fouling leading to track instability,
- Mapping soil, rock or fill layers in geological and geotechnical investigations, or for foundation design.

In Germany, Göbel et al. (1994) referred by Saarenketo performed GPR tests for determining: ballast thickness, layers interfaces, ballast pockets and mudholes location.
Jack and Jackson (1999) studied ballast layer along a track using two antennas with different frequencies, they found: clearer ballast interfaces indicating a clean ballast and thickness variations, affirmed GPR as a useful tool for identifying track sections with urgent necessity of rehabilitation.
Gallagher et al. (1999) found positive results for survey of ballast/subgrade interface, such as anomalies detection. Hugenschmidt (2000) reports a study developed on different alignments, evaluating the ballast thickness, fouled zones and ballast/subgrade interface depth. The conclusion was that radar survey is useful combined with traditional inspection methods. Recently, to determine the correlation between water content or fouling of a rail-road track and GPR signals, a full-scale railway track model was designed and constructed at the University of Massachusetts Amherst (Hamed et al. 2016). Different models were tested with moisture content conditions of dry, saturated and two points between these extremes. 450 MHz and 2 GHz frequency antennas were used to evaluate the different conditions. The results showed that the dielectric permittivity and frequency spectrum can be used as an indicator of fouling percentage and moisture content in a track.

3. Light Weight Deflectometer (LWD)

The light weight deflectometer (LWD) (Figure 1), is a hand portable device that was firstly developed in Germany to measure the soil in situ dynamic modulus. The LWD consists of a circular plate (150, 200, 300 mm diameter) loaded by a falling mass (10 - 15 - 20 kg).

Fig. 1.
Light Weight Deflectometer

The load resulting from the drop is dampen by a series of buffers, producing a transient force, dynamic in nature, simulating the effect of a moving vehicles. During the time interval of the load application, load and deflection time histories are recorded. The LWD, used for the trial test, was equipped with one geophone positioned in the center of the plate and 2 additional geophones that can be used for specific measures outside the plate.
When applied directly on the subgrade, data processing from LWD test is carried out according to Boussinesq theory for the estimation of the Elastic Modulus E by the following expression:

$$E = \frac{f \cdot \left(1 - \nu^2\right) \cdot \sigma_0 \cdot a}{d_0} \tag{1}$$

Where; f: the plate rigidity factor, a: is the load plate radius, r_0 and d_0 : respectively the peak values of the applied stress and the measured deflection under the center of the plate, ν: is the Poisson's ratio.

The influence of soil depth of LWD tests is considered to be 1÷1.5 diameters of the plate.
Neupan et al. (2016) from the university of Kansas estimated with LWD the resilient modulus of the substructure considering different combination of fouled ballast (10-40% by weight) and moisture content (1-10%). The test was conducted by reproducing in laboratory the real condition. Considering the various combination, they concluded that moisture content has the highest influence in reducing the bearing capacity.
Horníček et al (2014) used the LWD for the long-term evaluation of the condition of trial sections with the application of under-ballast geocomposites useful to avoid long-term problems of the track geometric position caused by the pushing of fine-grained soil from the subballast into the ballast bed (so-called pumping effect) and by the missing base layer between the ballast and the subgrade.
The exploitation potential of the Lightweight Falling Deflectometer is still increasing, and the results are aptly combined with other analytical and mathematical methods (Fernandes, et al., 2012; Burrow et al, 2007). In some cases, the impact device is used for a specific assessment of spots with problems resulting from the unstable geometric track position (Sharpe & Govan, 2014).

4. Case study

The trial site chosen for the trial run of the equipment is part of the Circumetnea railway track. Circumetenea manage about 120 km of local railway track in Sicily, by circumnavigating Etna volcano. The track is characterized by restricted gauge (950 mm instead the 1435 mm of the European standard) and a different composition of the superstructure which is going to be modernized with new concrete sleepers, new fasting system and the tamping of ballast. The area selected for testing is close to the Adrano nord railway station. It has the different conditions of tamped and not tamped ballast, wooden and concrete sleepers and cribs full with ballast or a complete lack of ballast in cribs.
The test was conducted on about 290 m of railway line. Specifically, the trial was conducted on three different sites:

- Site A: ballast with partial renovation and tamping,
- Site B: ballast in bad conditions,
- Site C: ballast recently replaced.

Thanks to this variety it was possible to test different railway track composition to test the ability of the equipment to catch the possible differences in: ballast layer thicknesses and their changes along the line (based on the presence of tamped ballast or old ballast), difference material for the sleepers, lack of presence of ballast in the cribs, different stiffness of the substructure based on the sleepers and ballast conditions. In the present experimental research work, an operative description of the equipment for the railway tests is presented. Preliminary results are used to draw potential field of application to provide a framework about the use of the equipment for railway track monitoring.

4.1. GPR test

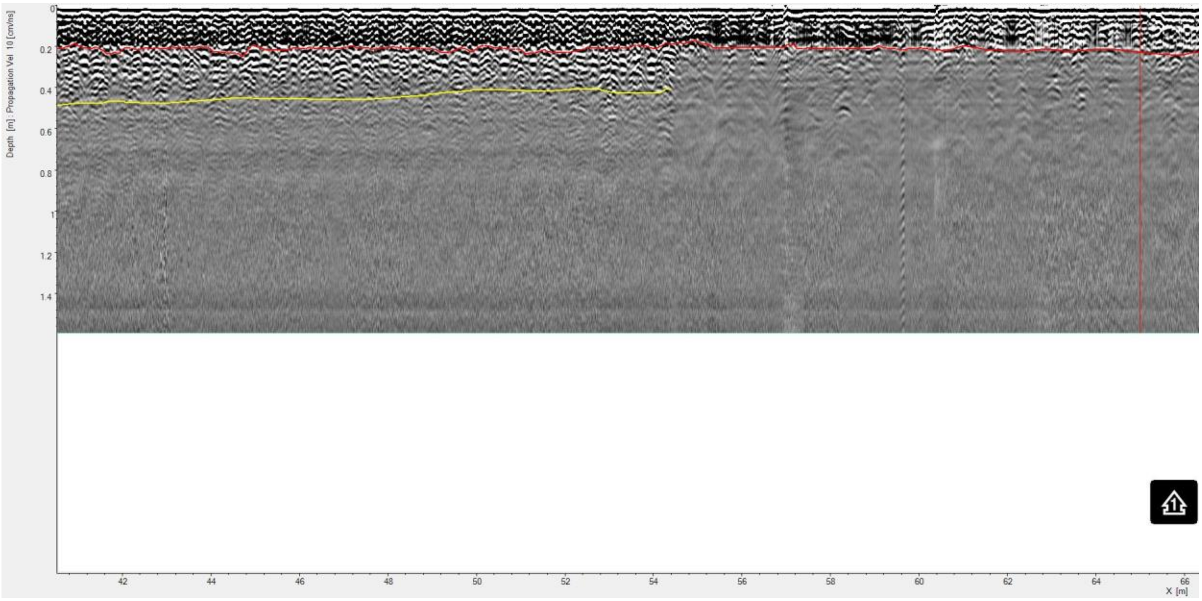
The GPR used in the trial, is a ground radar composed by two antennas of 600 MHz and 2GHz frequency. The wheel system was adapted for the test by modifying the wheels and the DMI configuration from road to railway application. Wheels are built with cone shape and made with resin for running on the railway track and avoiding electrical interferences. The chassis was adapted to the ground technology positioning the antennas very close to the surface of ballast (e.g. less than 10 cm) (Figure 2). In this configuration it was easy pushing the cart at a walking speed, but the system should be able to work at a speed up to 30 km/h.

Fig. 2.
Ground Penetrating Radar adapted for rail inspection (Site A)

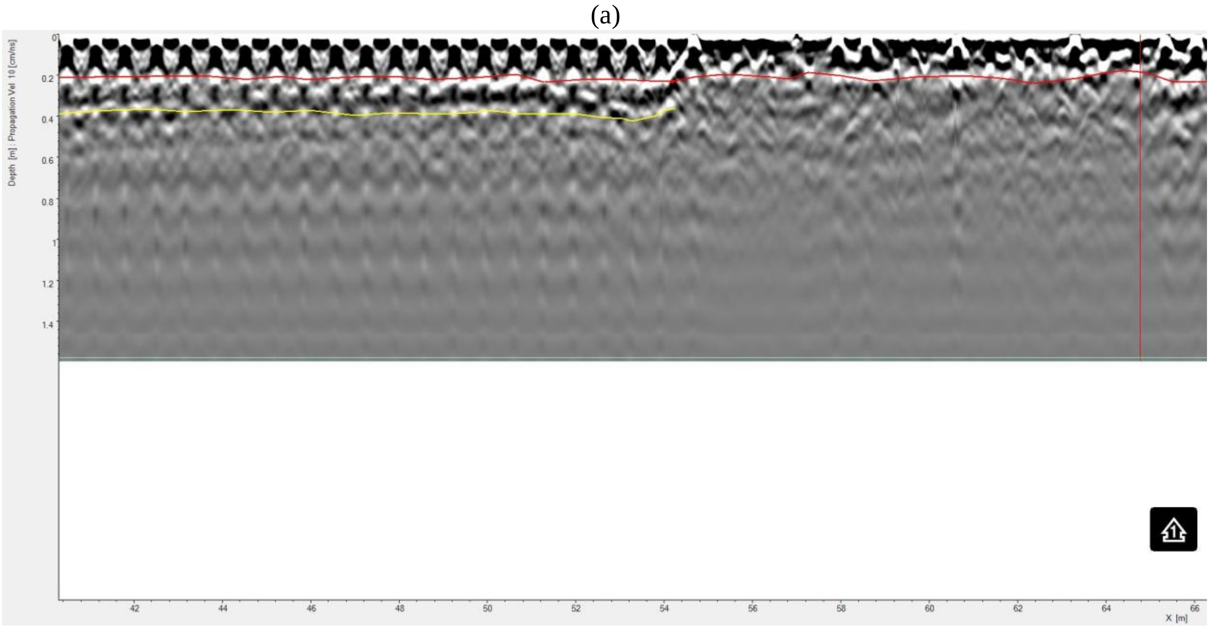
An example of radargrams collected by the two antennas is reported below. Fig. 3. reports the image of the radargram and the identification of the ballast layers.
To obtain this image the filters applied to radar map are:

- Identification of “zero point”, i.e.the transition air/ground. This operation is mainly used when scans are performed with antennas not in contact with the surface,
- Background removal: This command applies the Clear-X filtering algorithm used to remove continuous components along the X axis (horizontal direction) following user preset parameters, Depth min [m]=0 and Depth max [m]=10,
- Bandpass filter: this command applies a filter onto a frequency interval,
- Linear gain: is used to apply a filtering algorithm of the power equalization along a sweep to a selected radar map on the basis of an estimated linear attenuation.

The red line in the radargrams of Fig. 5 shows the transition from the tamped ballast characterized by a clear signal indicative of the contrast in dielectric constant from the ballast/subgrade interface, and the transition between the renewed ballast in site A (left) and the old railway track of site B (right).



(a)



(b)

Fig. 3.
Radar scans of the trial test with 2GHz (a) and 600MHz (b)

The presence of layers’ interfaces at different depths was detected by 600 and 2000 MHz antennas, as well.
As expected 2000 MHz is more effective in identifying layer’s interface at shallower depths that in this ballast application resulted limited at about 40 cm.
To identify deeper interfaces (e.g. ballast fouling), sub-ballast and subgrade moisture conditions the 600 MHz antenna resulted effective up to a depth of 1.5 m.

Also it's clear the signal different between the wooden and concrete sleepers. The wooden sleepers give a greater dispersion of the signal.
A comparison of the layer depths detected by the two antennas pointed out a Normalized Root Mean Square Error (NRMSE) of 20% when the 600 MHz antenna is used for the surface interlayer (absolute RMSE=0.05 m) and NRMS=31% when the 2GHz antennas is use to detect the layer at about 50 cm depth (absolute RMSE=0.16 m).

4.2. LWD test

LWD was used to estimate the stiffness of track foundation and sleeper support, as well. Tests were carried out positioning the loading plate in the middle of the sleeper and directly on the ballast between sleepers (crib position) and at the side of rail (Figure 4).

Fig. 4.
LWD test with plate in crib position (Site A) – LWD test with plate on the sleeper with additional geophones (Site A)

Results of drops on the sleeper, reported in Figure 5, show a clear variability in the measured deflections among the sites with different ballast conditions. Site with ballast of good quality (site C) reports lower deflections and higher uniformity.

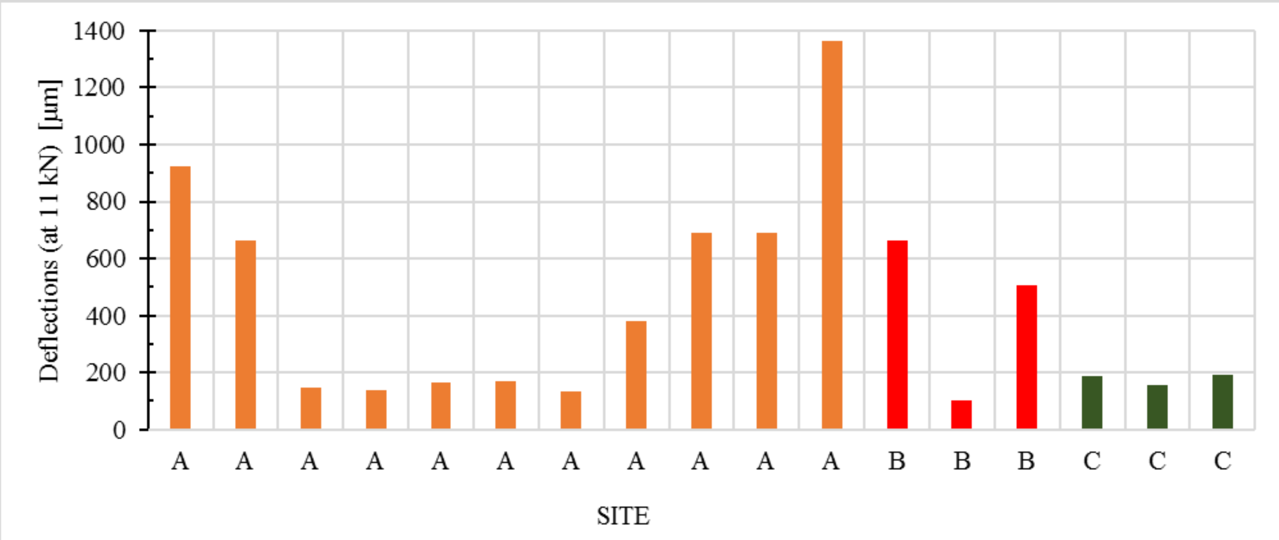


Fig.5.
Light Weight Deflectometer results

Deflection and load data can be used to calculate the track modulus. The track modulus, u, is defined as the applied force per unit length of rail per unit deflection (δ) (unit Pa) (Selig et al., 1994):

$$u = {}^{q}\!/_{\delta} \tag{2}$$

Where; *q*: the vertical foundation supporting force per unit length.
When the load is applied at the center of the sleeper, a simplified model of uniform vertical foundation supporting force per unit length can be assumed. This assumption is sustained by the uniform deflection of the sleeper detected during the test. The comparison of center plate deflection (Df1) with deflections measured at 20 (Def2) and 30 cm (Def3) (Figure 6) shows a negligible sleeper rotation is detected (i.e. 0.01% on average).

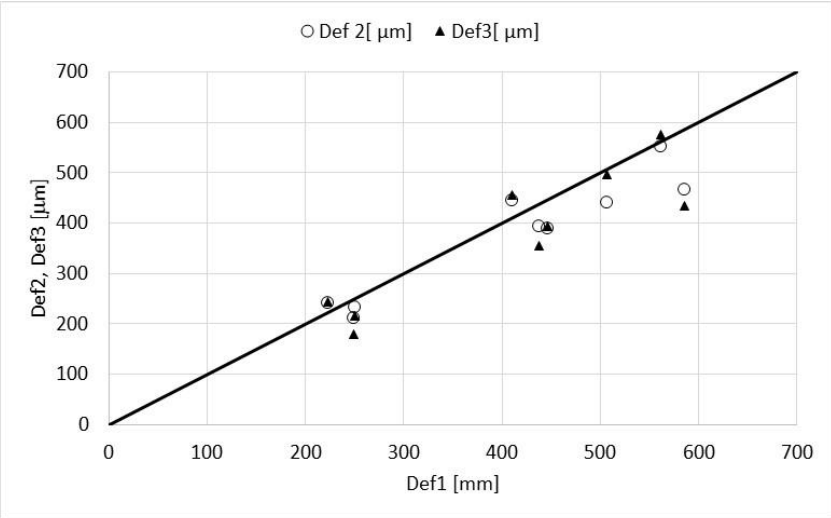


Fig. 6.
Deflection at the center of the loading plate (Def1) vs. deflections at 20 (Def2) and 30 cm (Def3) (load 11 kN)

Under this hypothesis, the track modulus can be derived from eq. 2 by using data of LWD test.
Track modulus was compared with ballast modulus estimated by Equation 1 with LWD test carried out directly on the ballast surface.
Results reported in Figure 7, pointed out how variability in ballast modulus is not necessarily reflected in the track modulus due to the interaction between rail, sleeper and ballast. Further, the sleepers may also have voids beneath them, which lead to large deflections with low loads (Sussmann et al., 2001).

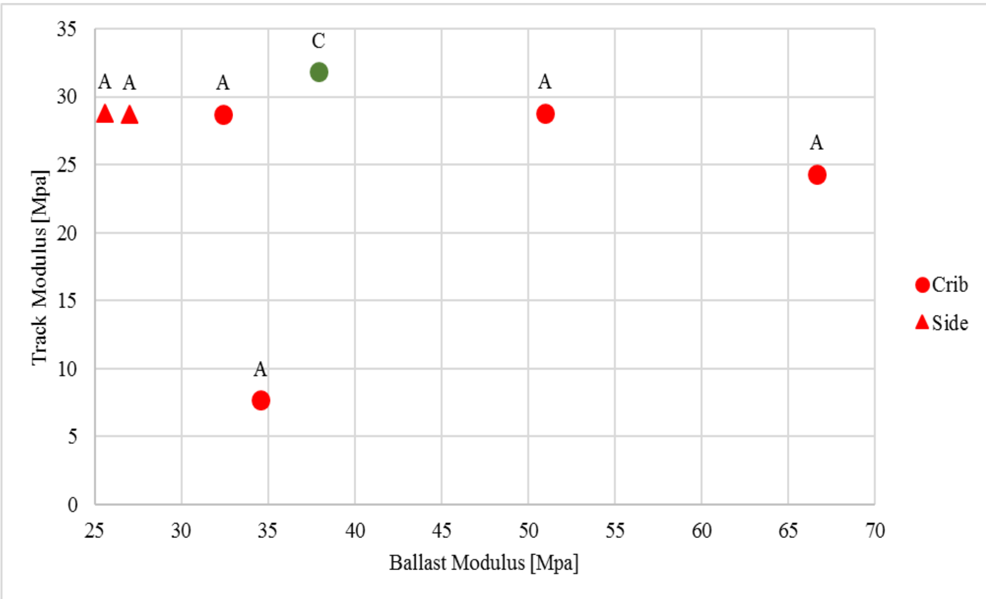


Fig. 7.
Ballast Modulus vs. Track modulus. Crib and Side positions. Sites A and C.

5. Lessons Learned and Conclusion

The main railway lines are by now monitored with high efficiency equipment based on the most advanced technologies in the field. In the case of local railway, which are not part of the main network, monitoring is still challenging in terms of costs and maintenance needs. Furthermore, a lack of a systematic monitoring brings to the impossibility to produce an effective long term track management system, by allocating budget where emergencies come. The present paper has explored promising solutions to overcome this limitation by using the equipment well known for road pavement monitoring, but not yet diffused in the railway management. Particularly the paper focused on the adaptation needed to use GPR and LWD on a railway track to test the bearing capacity and quality of ballast and track geometry. More specifically, the field tests were carried out on a local railway with reduced gauge of 950 mm. That condition gave the opportunity to test the equipment in an environment open to the introduction of such system in rail track monitoring for maintenance and Quality Control, as well

LWD showed its ability to identify variability in track stiffness. One requirement for stable track is a relatively uniform track stiffness that can support the applied vehicle loads. Track at locations where there are changes in track stiffness are hypothesized to result in accelerated track condition deterioration.
However, LWD is able to apply maximum loads of about 10 kN. At that limited load, deflection is mainly related to seating of the sleeper on the ballast. The seating deflection is defined as the deflection of the track under the light seating load, and the contact deflection is defined as the additional deflection that occurs from the seating load to the full load. In this way, the presence of void can be detected by variation of track stiffness at low loads.
The void deflection, is an indication of the slack in the track. Common reasons for high or variable void deflection are poor sleeper-to-rail fastener condition or the presence of fouled ballast, resulting in hanging ties.
Diagnosis of a track problem can be improved by implementing systems that measure the change in deflection of the track between two distinct, loads. For example, to eliminate the effect of voiding the secant stiffness may be calculated between 10 and 70 kN (axle load of 20 – 140 kN) (Eurobalt II). In the framework of the present paper, LWD may be used to reach the highest load-carrying capacity.
The main disadvantages of GPR systems in railway application are similar to the road one, because interpretation of radargrams is generally non-intuitive and considerable expertise is necessary to effectively design, conduct, and interpret GPR surveys.
By using a dual frequency system, the best of both is achieved, on this particular sites, the 2000Mhz provided high resolution data to approximately 0.4m depth, while 600Mhz provides greater depth penetration up to 1.5 m. These penetration depths are less than available in road applications due to the interferences produced by the sleepers at the top of the ballast surface.

Acknowledgements

LWD and GPR were acquired by the University of Catania in the framework of the Regional RESET project, funded by the Sicily Region Authority. The authors wish to express their gratitude also to “Ferrovia Circumetnea” for making available the railway sites.

References

American Society of Testing Materials, 2003. *Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications*, ASTM D 6951-03, ASTM International, West Conshohocken, PA.
Burrow, M.P.N.; Chan, A.H.C.; Shein, A. 2007. Deflectometer- based analysis of ballasted railway tracks. In *Proceedings of The Institution of Civil Engineers geotechnical Engineering*, 160(3): 169-177.
Cerniglia, D.; Garcia G.; Kalay, S.; Prior, F. 2006. Application of Laser Induced Ultrasound for Rail Inspection. Available from Internet: <http://www.uic.org>.
Daniels, D.J. 2004. *Ground Penetrating Radar*, 2nd Edition. IET, The Institution of Engineering and Technology, London, U.K.
Eriksen, A.; Gascoyne, J.; Al-Nuaimy, W. 2004. Improved Productivity & Reliability of Ballast Inspection using Road-Rail Multi-Channel GPR. In *Proceedings of Railway Engineering*.
Fernandes, J.; Paixão, S. F.; Fortunato. E. 2012. The Falling Weight Deflectometer: Application to Railway Substructure Evaluation. In *Proceedings of the First International Conference on Railway Technology: Research, Development and Maintenance*, Civil-Comp Press, Stirlingshire, UK.
Kashani, F.H.; Ho, C.L.; Clement, W.P.; Oden, C. 2016. Evaluating The Correlation Between Geotechnical Index And Electromagnetic Properties Of Fouled Ballasted Track By Full Scale Laboratory Model, In *Proceedings of the TRB 2016 Annual Meeting*.
Horníček, L.; Břešťovský, P. 2014. Using the Lightweight Falling Deflectometer for Monitoring Trial Railway Sections with Under-Ballast Geocomposites. In: Railway Condition Monitoring (RCM 2014). In *Proceedings of the 6th IET Conference*.
Hugenschmid, J. 1999. Railway track inspection using GPR, *Journal of Applied Geophysics*, 43(2-4): 147-155.
Gallagher, G.P.; Leiper, Q.; Williamson, R.; Clark, M.R.; Forde, M.C. 1999. The application of time domain ground penetrating radar to evaluate railway track ballast, *NDT & E International*, 32(8): 463-468.
Lee, W.; Lee, J.; Henderson, C.; Taylor, H.F.; James, R.; Lee, C.E. Swenson, V.; Atkins, R.A.; Gemeiner, W.G. 1999. Railroad bridge instrumentation with fiber-optic sensors, *Applied Optics*, 38(7), 1110-1114.
Minnesota Department of transportation, User Guide to the Dynamic Cone Penetrometer. Available from Internet: <http://www.dot.state.mn.us>.
NDT, C 2013. Rail Inspection. Available from Internet: <http://www.ndted.org/ >.
NDT, H 2014. A document outlining the emergence of the eddy current NDT inspection method as an important part of rail maintenance and safety.
Olhoeft, G.R.; Selig, E.T. 2002. Ground penetrating radar evaluation of railroad track substructure conditions. In *Proceedings of the the 9th Int’l Conf. on Ground Penetrating Radar*, 4758: 48-53
P. Ullidtz,1998. *Modelling flexible pavement response and performance*, Polyteknisk Forlag, Copenhagen, Denmark.

Sharpe, P.C.; Govan, R. 2014. The use of Falling Weight Deflectometer to Assess the Suitability of Routes for Upgrading. In *Proceedings of the Second International Conference on Railway Technology: Research, Development and Maintenance*.
Sussmann T.R.; Ebersöhn, W.; Selig E.T. 2001. Fundamental Nonlinear Track Load-Deflection Behavior for Condition Evaluation, *Transportation Research Record*, 1742: 01-2916.
Uzarski, D.R.; Brown, D.G.; Harris, R.W.; Plotkin, D.E. 1993. Maintenance Management of U.S. Army Railroad Networks-the RAILER System: Detailed Track Inspection Manual. Champaign, In *US Army Corps of Engineers; Construction Engineering Research Laboratories*.

INVESTIGATING THE INFLUNCE OF LONGITUDINAL GRADIENTS ON THE MECHANICAL BEHAVIOR OF FASTENING SYSTEMS OF RAILWAY TURNOUTS

Ahmed Abdelmoamen Khalil[1], Kamal Ghamry Metwally[2]
[1] *Benha University, Faculty of Engineering at Shoubra, Egypt*
[2] *Beni-Suef University, Faculty of Engineering, Egypt*

Abstract: The research presented in this paper aims to determine the influence of longitudinal gradients on the behavior of fastening systems of railway turnouts. This influence will be assessed through a case study in line No.3 of Greater Cairo metro network where 1 in 8 crossover has been installed in 2 % longitudinal slope. It has been observed that severe wear induced in the outer lead rail is out of tolerance in a short period after installation. Thus, the fastener steel clips on that rail have been damaged. Therefore, a sequence of analysis has been carried out in this paper to identify the causes of damaging of the clips. Clip`s material has been tested to determine its chemical composition; then stereoscopic photos of fracture surface of the clip (X8) have been taken. The vertical and transversal wheel loads of the wagons affecting the lead rail fastening system have been simulated using ANSYS software, thus results of the simulation have been analyzed in detail. Finally, a conclusion on the mechanical behavior of turnouts, a recommendation to minimize rail wear and to eliminate clips damaging have been introduced.

Keywords: railways, turnouts, longitudinal gradients, fastening systems, FEM.

1. Introduction

When a vehicle travels around a curve, centrifugal force will act on its center of gravity and forces it outwards. Centrifugal force results in an overturning moment and a stability moment is generated. When the train speed exceeds the balancing speed for the curve, the net result of these moments is to transfer a portion of the wheel load from the inner to the outer rail. The effect would then be to apply a greater load on the outer rail than on the inner. Additional flange force caused by excess, unbalanced centrifugal force would normally have little influence on the total flange force as it is usually considerably less than that portion of the flange thrust due to curving. Unbalanced centrifugal forces, however, can contribute significantly to vehicle rollover tendency, particularly when the speeds exceed the design speed of the curve and/or there is a track defect that results in a sudden increase in cant deficiency (Nilmani, 2012).
(RailCorp, 2011) introduced in a comprehensive study that when installing a crossover on a vertical gradient, the train going down-slope on a physical negative plane will experience a centrifugal force. The train will be constantly riding on the rail on the lower side of the slope or on the curved closure rail. The wheel flange will have a tendency to hit the switch point at the switch entry and the frog point during the wheel transferring at the frog. In addition, as the rail components of special trackwork are not fabricated with an inward rail cant, the down-slope train movement momentum through the crossover track and the train dynamic braking will exert a higher lateral force on the rail head. This could have a serious implication on operational safety, unless the train speed is reduced.
(Avinash Prasad, 2011) presented that turnout is the inherent weaker portion of the track work and thus the most sensitive to improper design, construction and maintenance. If proper design of diverging track of turnout is not done, it will lead to reduced operating speed in order to maintain good ride quality and component life. The diverging route of turnout has lower speed capacity, compared to mainline track. This given situation reduces the high speed potential of railroad vehicle negotiating the turnouts. Avinash stated that near point of switch in diverging track, switch rail creates kink in the alignment. Due to sudden change in direction of alignment, lateral force/acceleration is introduced. Normally turnout diverging lead curve is not provided with transition curve after the switch rail and before the crossing in conventional crossings. The switch rail can be straight as well as curved. If switch rail is straight, the curvature in alignment is only introduced at start and end of the switch rail. If switch rail is curved, then curvature starts at the switch entry point and ends at switch rail end before the closure rail. Normally, there is no provision of transition in switch rail, which leads to unbalance force at entry and exit of the switch rail. Normally turnout diverging lead curve is not provided with transition curve after the switch rail and before the crossing in conventional crossings. This will lead to unbalance forces. Due to lead curve radius, there is centrifugal force acting on the diverging portion of track.
Criteria for locating special trackwork on vertical gradients are system specific. The system operator should determine the criteria based on acceptable cross level difference on the diverging track on special trackwork, and the assessment of vehicle design, trackwork /alignment design, special trackwork design and track supporting structure. Special trackwork should be located on tangent track with 0% grade whenever possible. If it is necessary to locate special trackwork on grade due to track geometric restrictions, the design grade should[2] be as flat as possible. The track support structure for special trackwork located on a vertical gradient greater than 1.5% should consider the use of a direct fixation system to restrain movements contributed by thermal and lateral load phenomena. Special trackwork should have built-in anti-creep devices or be incorporated with a rail anchoring system in the track design to mitigate rail axial load that could change the turnout geometry due to thermal and vehicle dynamic braking. A crossover located on a

[2] Corresponding author: ahmed.khalil@feng.bu.edu.eg

vertical gradient higher than 1.5% is not recommended. 1.5% grade will introduce a cross level deficiency of 2.8 mm, which is approximately equal to the cross level construction tolerance of 2 mm. A crossover located on a grade greater than 1.5% could result in the diverging track becoming operationally unsafe. (Lam, 2010).

Movement on a curve generates wheel–rail double contact at the outer rail (Esveld, 2001; Lichtberger, 2011; Pyrgidis, 2016). This occurs due to the fact that when a train moves on a curve the railway wheelset does not have the freedom to be placed radially. Usually, the front bogie wheelset is displaced toward the outside of the curve. As a result the flange of the outside wheel hits on the inner edge of the outer rail. The generated guidance force forces both of the axle's wheels to slip toward the inside of the track, thereby generating friction forces on both rails. The first point of contact (on the outer rail) lays on the rail surface on which the wheel's tread is rolling, while the second point is the contact point between the wheel flange and the rail. A part of the vertical load is transferred from the wheel to the first point, building up the friction force. On the second contact point the rest of the vertical load and the total transversal force are transferred.

When vehicle speed exceeds the balance speed for the existing cant on a curve, the resulting centrifugal force has two separate effects, a) flange force acting against the outer rail, and b) increased load on the wheel running on the outer rail due to load transfer from the inner wheel. As the speed increases, so does the centrifugal force, and both flange force and wheel load on the outer rail increase together. Actually, centrifugal force acts on the center of gravity of the vehicle body. The body rolls on its suspension, transferring additional load onto the wheels on the outer rail. Wheel climbing is less likely to occur due to increase in centrifugal force provided that the path followed by the wheel is smooth and not interrupted by a track defect. The total change in direction at the entry is made up of the angularity of axle, the switch angle and the increase in switch angle from the theoretical toe of switch to the actual point of attack and is termed as angle of attack (Kumar and Mishra; 2013).

(TCRP; 2012) determined the desirable locations of turnouts and crossings. It was presented that the ideal location for turnouts, crossings and crossovers is in flat and straight sections of track. Also, it was concluded that if special trackworks should be laid in curves, cant, or vertical curves, the ability of the trackwork to perform in a satisfactory manner is compromised. So that, turnouts and crossovers are not placed in difficult locations and the overall requirements for special trackwork are minimized.

This paper focuses on investigating the influence of longitudinal gradients on the behavior of fastening systems of railway turnouts. Thus, analytical modeling and numerical simulation using ANSYS software have been carried out. Also, results of an experimental investigation carried out on a crossover placed in sloped section in Cairo metro tunnel, line 3 are presented.

2. Problem Statement

2.1. Case of Curved Tracks

A railway curve is a track which charges alignment without any sharp corners in rails. This change in alignment through curves is best attained through a circular curve. A circular curve has the advantage of uniform curvature i.e. uniform change of direction which makes the task of management of forces during change of alignment easier. Nature of forces experienced by vehicle is different on curved track as compared to straight tracks (Goel, 2010).

The vehicle passing over the curve continuously changes its direction over a curve. Due to the inertia, the vehicle tends to continue moving in the straight line but the forced change in direction of the movement by track gives rise to lateral acceleration acting outwards which is felt by the vehicle and all passengers inside. This acceleration is called centrifugal acceleration and the force due to the same is called centrifugal force (Chandra and Agarwal, 2007). To counteract the effect of the centrifugal force, the raising of outer rail with respect to inner rail is done. This raising of outer rail is referred to as cant. Due to the vehicle being on slope, a component of weight starts acting towards the lower rail. This component is called centripetal force and it acts opposite to the direction of the centrifugal force. The forces on a vehicle on the curve having cant are shown in Fig. 1.

2.2. Case of Turnouts

In some cases the designer is compelled to set out a turnout or a crossover (two turnouts) to change the direction of train movement to another branch line or to parallel track respectively. In turnouts, the straight and curved branch tracks are laid on same transversal sleepers. Therefore, it is impossible to provide the curved branch track with a cant. Thus, special track works, i.e. turnouts, crossovers …etc, are not provided with cant. Fig. 2 illustrates layout of sleepers in a right turnout.

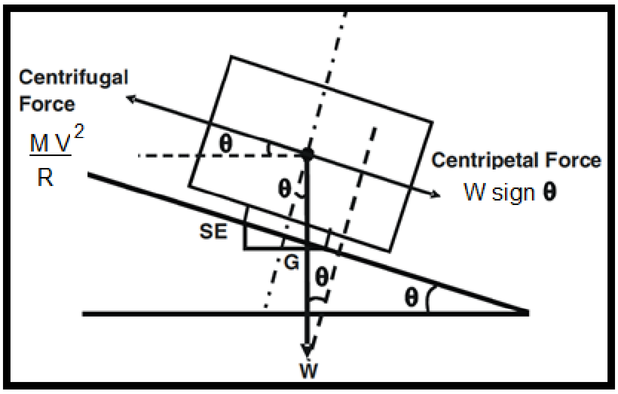


Fig. 1.
Forces Acting on Vehicle Moving on Horizontal Curve with Cant.
Source: Goel. A. (2010), Railway Curves

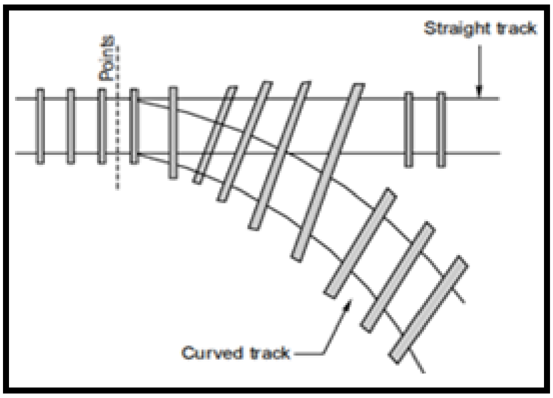


Fig. 2.
Schematic Layout of Sleepers in A right Turnout
Source: Chandra and Agarwal (2007), Railway Engineering

When turnouts are laid on longitudinal gradients, the elevation of the contact point of the train wheel on the outer rail of the diverging branch track will be lower than the elevation of the corresponding contact point on the inner rail. This phenomenon occurs due to precedence of the outer wheel to the inner wheel during running on a curve that is laid on a down gradient (G). It is illustrated from Fig 3 and Fig. 4 that a negative cant (C, i.e. difference in elevations of points 1 and 2) will be produced in turnout A, whereas; a positive cant in turnout B. Fig. 4 shows that point 1 is lower than point 2 and points 2, 3 and 4are at the same level.

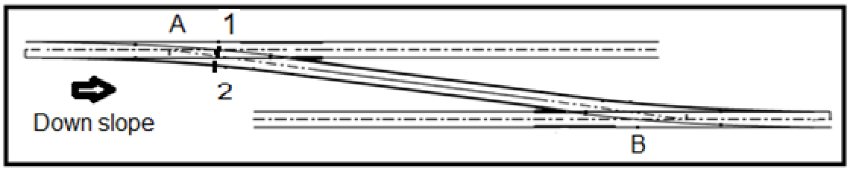


Fig. 3.
Layout of Turnouts (Crossover) on Down Gradient

As a result of running of trains on the down sloped turnout (A), the centripetal force will change its direction to the outer rail as illustrated in Fig. 5. So, the diverging route of turnout could produce high lateral forces and accelerations due to centrifugal and unbalanced forces. Also, there will be a tendency for the wheel to slide towards the lower rail.

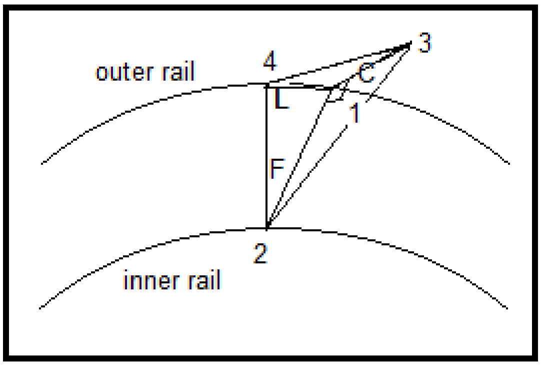


Fig. 4.
Negative Cant Production

The normal deterioration of the track surface, combined with any imperfection in the installation or manufacturing of the rails will compound the effect of the negative cant on the diverging track. In addition to increasing the straining actions and surface defects such as corrugations and wear in the outer rail, these forces impacting negatively on the fastening system as they produces higher induced stresses; so that they may cause damage of clips and screw spikes. K-type fastening system is shown in Fig. 6.

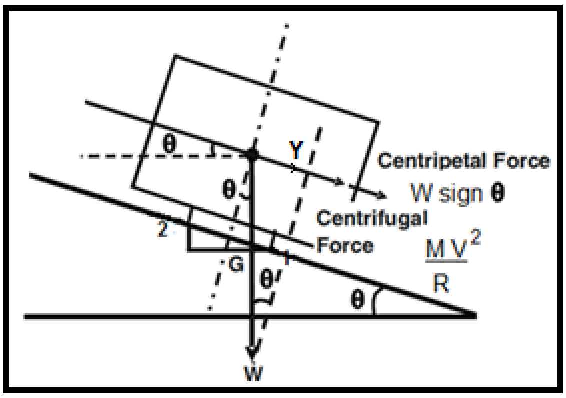


Fig. 5.
Exerted Forces in Case of Down Sloped Turnout

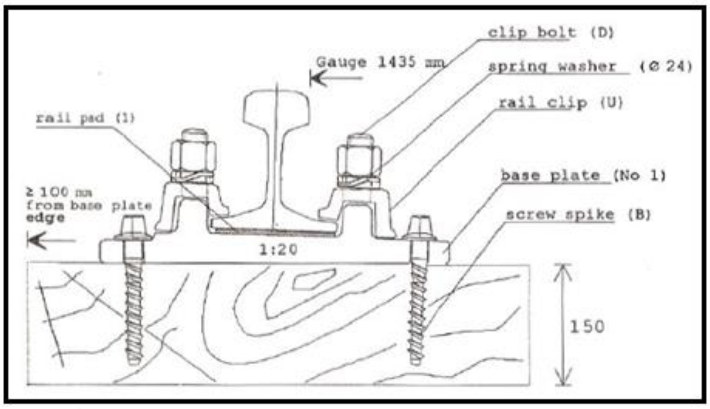


Fig. 6.
Dimensions (mm) of K-Type Fastening System
Source: ENR, Guidelines of Railway Tracks

3. Material and Data

3.1. Experimental Works

A stereoscopic investigation on a failed clip; that used in a down sloped turnout inside the tunnel of Greater Cairo Metro; has been carried out in laboratories of the Central Metallurgical Research and Development Institute to determine locations of initiation fracture. Fig. 7 illustrates a stereoscopic photo (X8) for the failed U-shape clip. Also, chemical analysis was carried out by Spectra analytical instrument model ARL 3560. Table 1 represents the chemical composition of 3 sparks and mean value for a sample of the same failed clip.

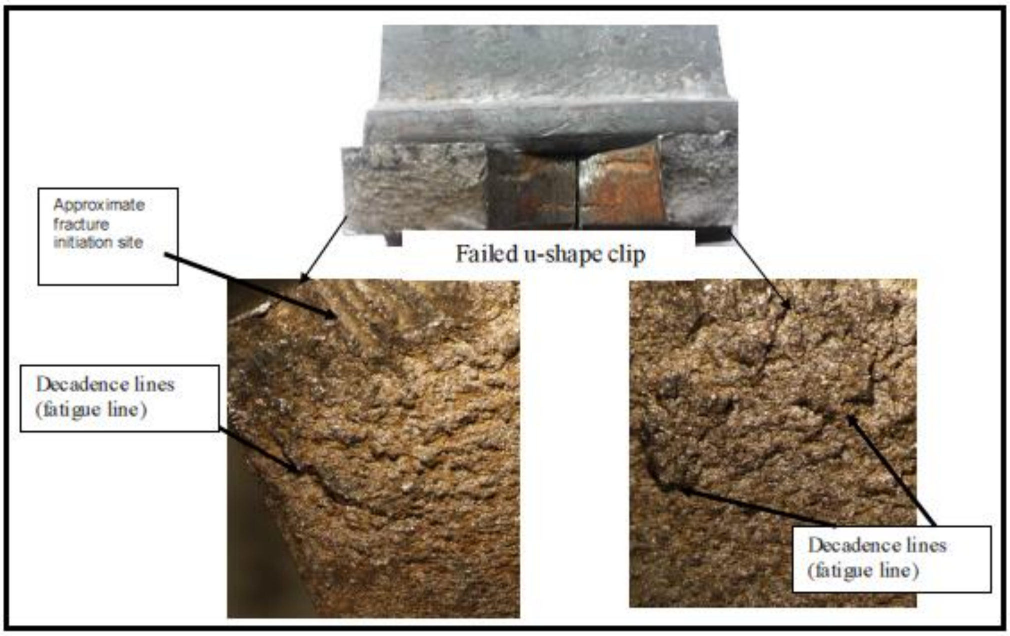


Fig. 7.
Stereoscopic Photo (X8) for the Failed U-Shape Clip in Down Sloped Turnout.
Source: Central Metallurgical Research and Development Institute

Table 1
Chemical Composition for A sample of the Failed Clip

Element wt%	C	Si	Mn	P	S	Cr	Ni	Al	Co	Cu
Spark 1	0.167	0.185	0.527	0.00907	0.00944	0.0145	0.0087	0.0134	0.0014	0.0168
Spark 2	0.162	0.189	0.527	0.00866	0.00987	0.0148	0.00938	0.0135	0.0023	0.0168
Spark 3	0.164	0.185	0.524	0.00824	0.00101	0.0149	0.00862	0.0134	0.0021	0.0165
Mean	0.164	0.186	0.526	0.0087	0.0098	0.015	0.0089	0.0134	0.00193	0.0167

Source: Central Metallurgical Research and Development Institute

3.2. Simulation Works

A nonlinear numerical simulation for the resultant transversal force (H) acting on the outer rail has been carried out using ANSYS software. In this simulation, the vertical load was taken 75 and 120 kN in two different cases. Values of the transversal force were assumed to be increased incrementally in the range from 30 to 70 kN and from 40 to 110 kN for the first and the second cases respectively. The fastening system was simulated by multiple contact elements to achieve the interaction between the different elements. Geometry and meshing of the finite element model are shown in Fig. 8; whereas samples of the simulation output for case of 75 kN vertical load and 30 kN transvers force are shown in Fig. 9 (a), (b) and (c). Material properties of the fastening system were considered as follows:

Density of steel (γ) =78.5 kN/m^3
Elastic modulus (E) =21000 kN/cm^2
Poisson ratio (ρ) =0.30
Modulus of rigidity of steel (G) =8000 kNlcm^2
Rubber pad stiffness =120 kN
Tensile strength of rubber pad =20 MPa

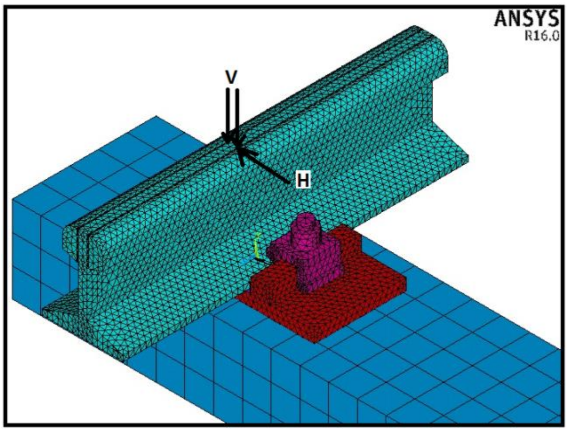


Fig.8.
Finite Element Model

4. Results and Discussion

4.1. Results of the Experimental Work

The chemical composition emphasizes that the material of the sample is structural and constructional steel alloy No. 1.0487. The photos of the crack surfaces show that crack is initiated from the upper surface of the clip and propagated throughout the thickness of the clip. It is also noticed that the cracked surface contains little feature of the decadence lines (fatigue line).

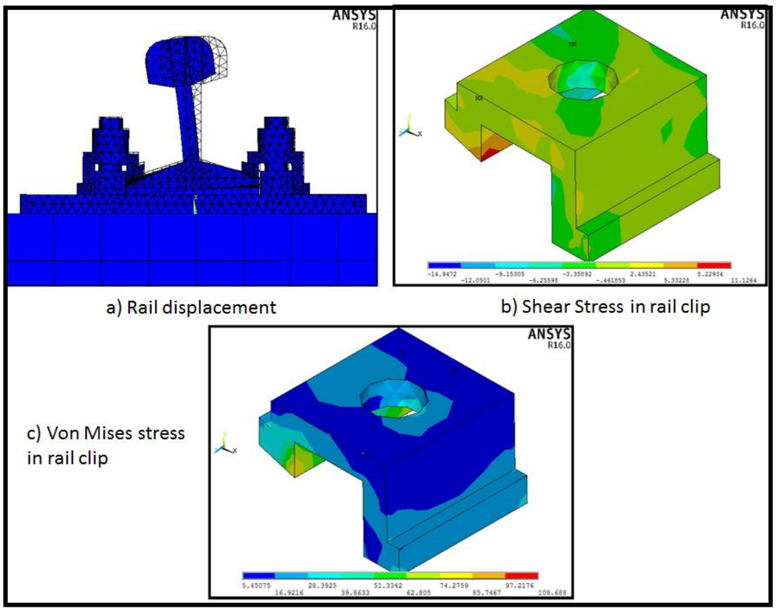


Fig.9.
Samples for Solutions of ANSYS

4.2. Analytical Modeling

Analytical model for the transversal force (H) on the outer rail can be deduced as follows:
Referring to Fig. 4, let the distance between points 1 and 4 = L (mm), negative cant = C (mm), distance between points 1 and 2 = distance between center lines of rails = 1500 mm, angle of axle angularity = < F, and W = Axle weight (kN), v = train speed (km/h) and g = gravity acceleration = 9.81 m/s^2.

$G\% = C/L$

$C = L \times G/100$ mm

$L = 1500 \times \mathrm{Tan} < F$ mm

But, $< F$ = Axle angularity = turnout angle

$C = 1500 \times G/100 \times \tan < F$

$= 15 \times G \times \mathrm{Tan} < F$ ……………………… (1)

Referring to Fig. 5,

Centrifugal force = $M \times v^2/R$

$= (W/g) \times v^2/12.96\ R \quad \text{kN}$

Centripetal force = $W \times \sin\theta = W \times \tan\theta \quad \text{kN}$

Where, $\tan\theta = C/1500$

Transvers friction force = $Y = \mu \times W/2$

Where, μ = transvers coefficient of friction between train wheel and rail.

$\mu = 0.25$

$H = \mu \times W/2 + (W/g) \times v^2/12.96\ R + W \times C/1500$……………………….. (2)

Substitute from eqn. 1 in eqn. 2.

$H = \mu \times W/2 + (W/g) \times v^2/12.96\ R + (15\ W \times G \times (\text{Tan} < F)) / 1500$

Thus, the following model can be introduced for the resultant static transversal force acting on the outer rail of turnouts.

$H = \mu \times W/2 \times \cos\theta + (W/g) \times v^2/12.96\ R + (W \times G \times (\text{Tan} < F)) / 100$ ……………….. (3)

To obtain values of (H) which correspond to different values of (G), the model in (3) for turnout 1 in 8 and the case study of greater Cairo metro line 3 where ($v = 35$ km/h, $W/2 = 75$ kN, $R = 154.525$ m and $F = 7.125^0$) is applied. The obtained values are given in Table 2.

Table 2

Values of H- Load Corresponding to Different Grades (G).

G %	1	2	3	4
1st Term (Sliding force)	18.75	18.75	18.75	18.75
2nd Term (Centrifugal force)	9.353	9.353	9.353	9.353
3rd Term (Grade force)	0.187	0.375	0.561	0.748
H- Load (kN)	28.290	28.478	28.664	28.851

4.3. Simulation Results

To determine the effect of the transvers force (H) on the stability of the fastening system, the relationship between the force (H) and the rail displacement is plotted in Fig. 10 (a) for case of 75 kN vertical load. Also, the impacting of force (H) on the shear and principle stresses (Von Mises) in inner rail clip is illustrated in Fig. 10 (b) and Fig. 10 (c) respectively.

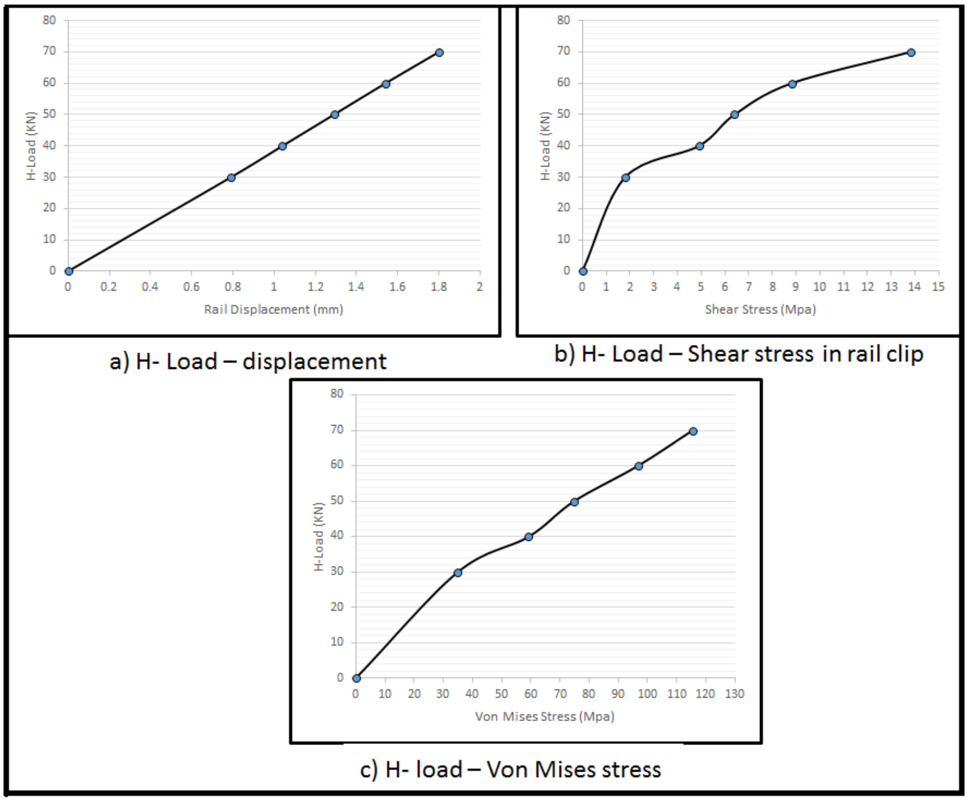


Fig. 10.

Effect of H- Load on Rail Displacement (a) and Inner Clip Stresses of Outer Closure Rail (b), (c).

4.4. Discussion

It is indicated from recorded values in Table 2 and Figs. 9 and 10 that values of shear and principle stresses at rail clip are kept below the allowable values even in case of maximum allowable grade for electrified lines (G= 4%). For G = 2% (Case study for Cairo metro line 3), maximum static H - force = 28.478 kN. As the running speed of trains on the turnout is 35 km/h, the dynamic factor according to Zimmerman = 1.04. Therefore the maximum H-force = 29.64 × 1.04 = 29.64 kN. Thus the corresponding rail displacement = 0.8 mm, maximum shear stress at the upper surface of inner rail clip = 1.8 Mpa and 10 MPa at the contact surface between rail and inner clip. The maximum principle stress (Von Mises) in the upper surface of the inner rail clip = 35 Mpa and 100 Mpa at the contact surface between rail and inner clip. Thus, values of the transvers load (H) are not significantly influenced by increasing the longitudinal grade (G). But the major effect is generating the sliding and centrifugal forces which acting towards the outer rail. These unbalanced forces cause higher rail displacement and vibrate the fastening system. As a result of the produced contact pressure between rail base and inner clip (100 MPa) as shown in Fig. 9 (c), the clip is lifted up. Therefore, the induced vibrations and fatigue stress initiate internal cracks in the inner clip of the outer rail.

5. Conclusion

This paper focused on investigating the influence of longitudinal gradients on the mechanical behavior of fastening systems of turnouts. So, different analyses have been carried out in this paper; analytical modeling, finite element modeling and experimental works. The conclusion of the results is summarized as follows:

1- Longitudinal grades cause negative cant in the outer closure rail of the down slope-start turnout of crossover; vice versa, they cause positive cant in the slope–end turnout.
2- Values of the transvers load on the outer rail head of the down slope-start turnout are not significantly influenced by increasing the longitudinal grades.
3- As a result of longitudinal grades sliding and centrifugal forces acting towards the outer closure rail of the down slope-start turnout are generated.
4- Induced vibrations and fatigue stress initiate internal cracks in the inner clip of the outer closure rail of the down slope-start turnout.
5- A turnout located at start of down-slope for diverging train movement is not recommended.

Acknowledgements

The authors are grateful to the staff of Cairo Metro Company as well as the technicians in the Central Metallurgical Research and Development Institute in Cairo.

References

Avinash Prasad, 2011. Turnout design: High Diverging Speed in the Same Footprint. In *Proceedings of AREMA Conference*.
Chandra and Agarwal, 2007. *Railway Engineering.* Oxford University Press. India. 594 p.
Chiristos N. Pyrgidis, 2016. *Railway Transportation Systems*, CRC Press, UK. 461 p.
ENR, 2008. *Guidelines of Railway Tracks*. *Egypt.*
Esveld, C. 2001, *Modern Railway Track*, 2nd edition, MRT-Productions, West Germany. 740 p.
Francis, T.L. 2010. Considerations for Installing-Special-Trackwork-on-Vertical-Gradients. In *Proceedings of Rail Conference, Building LRT Urban Track Structures 2010, USA.*
Goel, A. 2010. *Railway Curves*. Indian Railways Institute of Civil Engineering. M.R. &Co. Pune, India. 229 p.
Lichtberger, B. 2011. *Track Compendium: Formation: Permanent Way, Maintenance, Economics*, Eurail Press, Hamburg. 621 p.
Nilmani, 2011. *Tracking and curving by railway vehicle: Issues in heavy haul*. Iricen, Pune, Available from Internet: <http://documents.mx/documents/tracking-and-curving-by-railway-vehicle.html>.
RailCorp Engineering, August 2011. *Track and Rolling Stock, Derailment Investigation*. Engineering manual, 94 p.
Subin Kumar, Ashish Mishra, 2013. Design of High Speed Turnout More Than 250 km/h. In *Proceedings of AREMA Conference 2013.*
TCRP, RPT 57, 2013. *Track design Handbook for LRT*, chapter 6, 6-8.

POSSIBILITIES OF DEVELOPMENT OF RAILWAY SIDINGS IN THE SLOVAK REPUBLIC

Vladislav Zitrický[1], Lenka Černá[2], Ján Ponický[3]
[1,2,3] *University of Žilina, The Faculty of Operation and Economics of Transport and Communications, Žilina, Slovakia*

Abstract: Railway sidings are currently one of important part of the railway operation and their uses directly influence the position of railways in the transport market. Without the support for railway siding operation it is impossible to develop the railway freight transport and then fulfil the objectives of European Commission, which are presented in the "White Paper - Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system". Trend of the interest in the rail transport has been decreasing for last 25 years and this fact influences the transport volume in railway siding operation. 25 years ago Slovak economy changed from a planned to a market economy and since then the number of active railway sidings has been decreasing continually. Therefore it is necessary to find effective methods for support and development of railway transport in the Slovak Republic. In the Slovak Republic there are many railway sidings which have an active licence for operation but have no transport performance in the railway transport. There are several reasons for this situation, but the most important ones are financial requirements for railway siding operation, prices in railway freight transport and routing of freight flows, too. Elimination of these adverse factors is presented herein. This paper is focused on the possibilities of development of railway sidings operation in the Slovak Republic. The article contains analysis operations conditions of railway sidings as well as the position of railway sidings in the railway freight transport, and their influence on the performance of the railway transport. In the article there are presented factors of gradual performance decline and proposals for development of railway sidings operation.

Keywords: railway siding, transport, development, Slovak Republic.

1. Introduction

Currently the number of active rail sidings influences the position of rail freight transport in the Slovak transport market. Trend of active rail sidings, which participate on the rail transport performance, has been decreasing for last 25 years. This fact is caused by the change of a political system in the Slovak Republic and by the transformation of the national economy from a planned to a market economy. The paper includes an analysis of railway sidings operation in the Slovak Republic and an analysis of a relationship between transport performance and the number of active railway sidings (or the gross domestic product), and it also includes a proposal for development of railway sidings.

The scientific methodology used in the paper is divided into several steps and it is focused on the proposal regarding the operation of railway sidings development in the Slovak Republic. The first step of the methodology defines issues of railway sidings and objectives of research. The research part includes an analysis of railway sidings operation, transport performance in the Slovak Republic by the transport mode, causes of the decline of active railway sidings, the gross domestic product and a definition of a correlation analysis. The correlation analysis is used to determine a statistical dependence between selected quantitative variables.

The realisation phase of the methodology includes data collection and its interpretation, and mathematical expression of a correlation coefficient. The end of the paper is oriented on the proposal for development of railway sidings operation by the RFID technology for an information system that is used in the railway operation, state support for rail operation and possibilities of connecting logistic centres in the Slovak rail network. Proposals for development of railway sidings are based on the analysis and come from the research literature.

2. Transport Market and Challenges of Railway Sidings in the Slovak Republic

2.1. Gross Domestic Product and Transport Market in the Slovak Republic

As Ľoch and Dolinayová wrote the transformation of Slovak national economy after the year 1990 brought a gradual increase of the gross domestic product. This increase was influenced mainly by political changes. Political changes supported the possibility of the Slovak Republic to enter into the European Union and it is part of global economy.

In the Figure 1 we can see a continuous increase of the gross domestic product of the Slovak Republic. Based on the presented figure we can say that the growth rate of the gross domestic product featured a relative increase, which reflects the percentage ratio of the absolute gross domestic product and the achieved level of a real output in the previous period. The increase of the gross domestic product has also influenced transport performance in the Slovak Republic and has brought new trends which must gradually be solved in the transport market. The biggest problem which Slovak Republic had to solve in the era of transforming the economy was creating a new transport condition for all modes of transport. New transport and market conditions also meant new possibilities for a private sector – liberalisation of transport market. Firstly the road transport market was liberalised; which was a relatively quick process. Liberalisation of rail transport market was a long process and had some negative impacts on the transport performance in rail transport. Currently all modes of transport in the Slovak Republic have been liberalised in the

[1] Corresponding author: vladislav.zitricky@fpedas.uniza.sk

market and a competitive environment has been created. Competition exists not only between transport modes, but now it is a free competition also between the carriers of each transport mode.

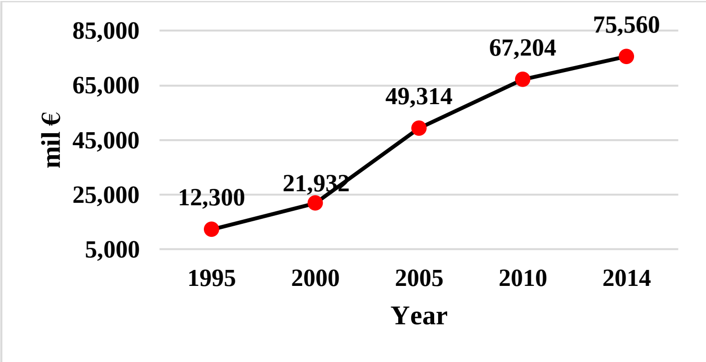


Fig. 1.
Gross Domestic Product in the Slovak Republic
Source: (Yearbooks of transport, Slovak Republic)

Political and economic changes have also transformed transport market during last 25 years. Road transport gradually obtained a majority position in the transport market. In the Table 1 and Figure 1 we can see a significant increase of their transport performance. On Slovak railway sidings there is realised a main part of rail freight transport performance, even though the performance has been decreasing for last years. They are mainly on bulk substrates coming from the extraction, transport of chemicals, iron, wood, automobiles, etc. Based on the statistical data published in Yearbooks of transport, statistical database of data-set was created, which includes data from years 1995, 2000, 2005, 2010 and 2014. The overview of transport performance is in the Table 1.

Table 1
Performance by the Transport Mode in the Slovak Republic

Indicator/Year		1995	2000	2005	2010	2014
Number of railway sidings		643	575	506	393	302
Transport performance [mil. net ton km]	Road transport	5,158	10,042	22,550	27,411	31,304
	Railway transport	13,764	11,234	9,463	8,105	8,829
	Water transport	1,468	1,383	680	2,166	684
	All modes of transport	20,390	22,659	32,693	37,682	40,817
Gross domestic product [mil. €]		12,300	21,932	49,314	67,204	75,560

Source: (Yearbooks of transport, Slovak Republic)

Dolinayová, Ľoch and Kanis declare that the greatest amount of goods transported is realised by the road transport and till the year 2005 it had a fluctuating character. After the year 2005 to year 2010 freight transport had a lower growth rate. It was caused by the great world economic and financial crisis, which started in 2009. After the crisis the trend of transport volume in road transport grew again. Transport volume in rail transport had a decreasing character till the 2010 and after this year this negative trend was stopped, and in the year 2014 the transport volume was slightly higher than in the year 2010. In the Figure 2 we can see a graphical representation of transport volume for the reported period.
Water transport is a minority transport mode in the Slovak Republic, as Jurkovič and Dávid said, and its transport volume is negligible opposite to road and rail transport.

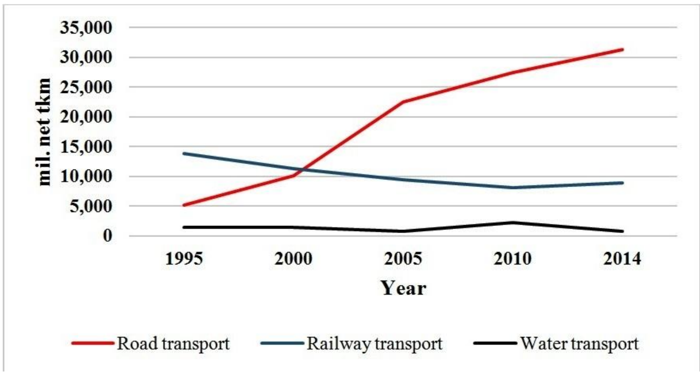


Fig. 2.
Transport Performances in Freight Transport
Source: (Yearbooks of transport, Slovak Republic)

2.2. Position of Railway Sidings in the Transport Market in the Slovak Republic

Kejíková and Klapita and also Abramovič, Brnjac and Škrinjar declare the importance of railway sidings in rail operation, and their status is of a significant meaning. Transport volume on the railway sidings creates the majority share on the whole rail transport volume. From this fact it is necessary to monitor and develop the area of railway sidings and at the same time transport market conditions have to be taken into account. The decreasing trend of rail transport volume in the European Union has been reflected in the Slovak Republic, too.
Most of railway sidings have a still active licence for operation, but their performance is minimal or none. It is caused by the financial conditions for operation, pricing in the rail freight transport and orientation of transport flows. Industrial companies in the Slovak Republic transported the majority of goods by the rail transport till the 90s in the last century. Political and economic changes have brought a decreasing trend of transport volume in rail transport until these days. On the other hand transport volume in road transport has had a growing trend. Among results of this fact there is an increase of congestion and overloading of highways and first class roads. Most of railway sidings were cancelled or function in a restricted regime only. The destiny of most non-active railway sidings is considerably problematic. Several railway sidings are available for sale, but there is no interest in buying them on the real market. Some railway sidings have an unknown owner, because the subject stopped his business many years ago.

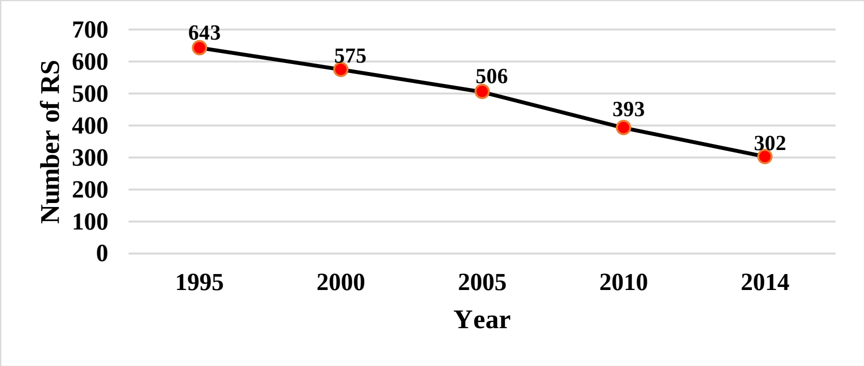


Fig. 3.
The Number of Railway Sidings in the Slovak Republic
Source: (Yearbooks of transport, Slovak Republic; Lovíšek and Dolinayová, Daniš and Čamaj)

In the Figure 3 there is an overview of development of the number of railway sidings for the reported period. The number of railway sidings has had a decreasing slope. Despite of this fact railway sidings still have a majority share on the rail transport performance. In the Figure 4 we can see a share between single wagon loads and block trains which are operated between railway sidings.

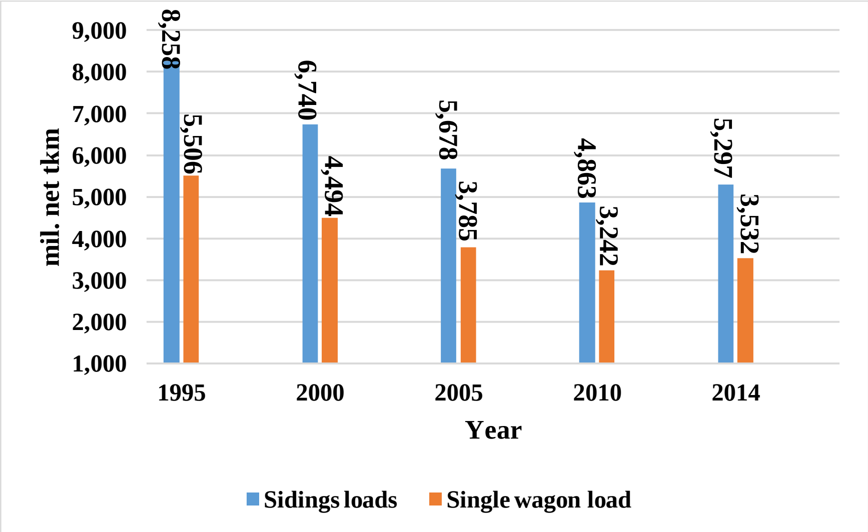


Fig. 4.
Performance of Rail Transport
Source: (Study and Survey of Railway Sidings, ŽSR)

Based on the Study and Survey of ŽSR on railway sidings that was realised between the owner of railway sidings and carriers we can see an interesting usage of railway sidings. However the survey also showed a great weakness of this transport type. It revealed the weakness on the side of an infrastructure manager (ŽSR), railway undertakings (national and private) and also of the owners of railway sidings. The most relevant weaknesses are: data update by means of communication, efficient usage of information and update of transport condition (technical and operation). Another great problem was identified in the form of a small state support for the transport area, specifically for railway transport. For example many users of railway transport (not only the owner of railway sidings) expect a more effective support from the state for the rail infrastructure.

2.3. Correlation Analysis

Based on Benko's definition "Correlation is a mutual linear relation (dependence) of two random variables X and Y. This relation can be direct (if one variable increases, then second variable increases, too), or indirect (with one variable growth there is a fall of the second one)" (http://fstroj.uniza.sk/kam/orsansky/pdf/zakladystatistiky.pdf)
Mathematical calculation, which results in numerical data talking about the dependence of two or more elements of statistical data-set, is called a correlation number. The correlation coefficient r(x, y) represents the dependency of two variables x and y from the statistical data-set. This dependence is expressed with a statistic covariance cov (x, y):

$$\mathrm{cov}_{(x,y)} = \frac{1}{n-1} * \sum_{i=1}^{n} \left(x_i - \bar{x}\right) * (y_i - \bar{y}) \tag{1}$$

After calculating cov (x, y) we can further determine the correlation coefficient according to the formula:

$$r_{(x,y)} = \frac{k_{(x,y)}}{s_x * s_y} \tag{2}$$

Palkovič says the value of correlation coefficient expresses a linear degree of dependency of variables x and y. Value of correlation coefficient is from -1 to 1. When values of correlation coefficient are 0, there exists no relation, i.e. no dependence between the variables. When the value is 1, then the variables are directly dependent. When the value of correlation coefficient is -1, then the variables are indirectly dependent.
In the Figure 5 the correlation relationship is shown and the correlation coefficient between the gross domestic product of the Slovak Republic and total transport volume in Slovakia is calculated.

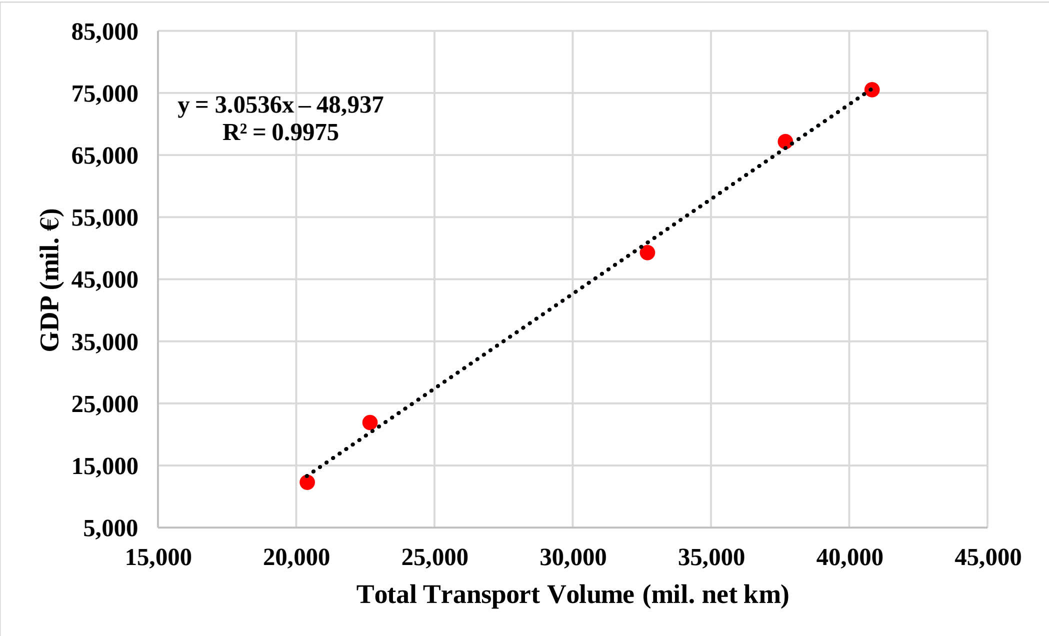


Fig. 5.
Relation between Total Transport Volume and the Gross Domestic Product
Source: (Authors; based on the statistical data)

Based on the calculated correlation between the gross domestic product and total transport volume in the Slovak Republic we can claim a very strong dependency. Correlation coefficient has a value 0.999 and the Pearson's coefficient is 1.00. Variability of the gross domestic product is 99%. The result of correlation analysis shows that the gross domestic product and total transport volume are changing their direction. In this case it is obvious: any increase of the gross domestic product means the growth of transport performance.
In the Figure 6 there is a correlation analysis between the number of railway sidings and transport volume in the Slovak Republic.

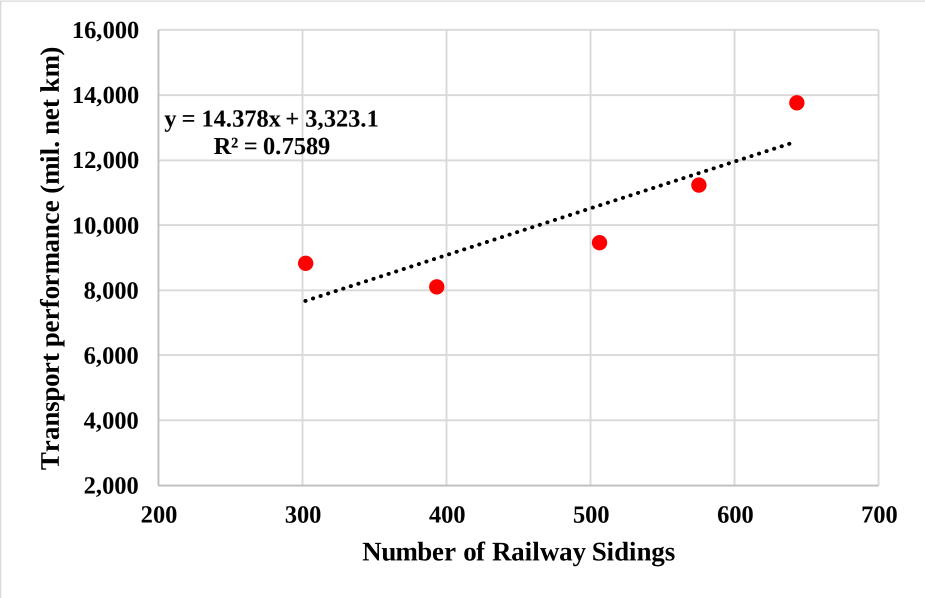


Fig. 6.
Relation between Rail Transport Performance and the Number of Railway Sidings
Source: (Authors; based on the statistical data)

Simple linear correlation between the number of railway sidings and rail transport performance is very strong for the reported period. Correlation coefficient has a value 0.871 and Pearson's coefficient is 0.87. Based on the calculated correlation we can say that if there were no railway sidings in the Slovak Republic, the transport performance in rail freight transport would be 3 323 mil. net kilometres per year. Variability of the transport performance is 76%. Both correlations' coefficients have values that represent the highest positive correlation. Both computed values (number of railway sidings and transport volume) are changing together by the same direction and they have a strong dependency.
Results of correlation analysis show a strong dependency between rail freight transport performance and the number of railway sidings. Therefore it is necessary to directly support development of railway sidings infrastructure and consequently a positive development of the whole freight rail transport can be expected. The result will be the development of rail transport based on the determined objectives of the European Union, which are contained in the White Paper: Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, as said Gašparík, Abramivič and Halás.

3. Proposals for Development of Railway Sidings

Proposals for development of railway sidings in the Slovak Republic are oriented on three points. First proposal consists of using the RFID technology. Second is about the state government supporting the railway sidings and third proposal describes possibilities of connecting logistics centres in the railway infrastructure.

3.1. RFID technology

An efficient management of railway sidings in Slovakia lies in the use and processing of information. It is however one of the weaknesses of rail operation in railway sidings. These weaknesses are also mentioned in the survey described in chapter 2.2 of this paper. Based on this fact we describe a possibility to use RFID technology in railway sidings as one factor of support to develop rail operation on railway sidings.
Support of applying RFID technology to railways sidings requires the existence of an information system for railway sidings (ISRS). Currently this condition is a problem on railway sidings in the Slovak Republic, as Lovíšek published in his dissertation thesis, because main railway sidings operators have an own information system (for example the company US Steel, a. s., or Slovnaft, a. s.); small railway sidings don't have any information systems and the communication between rail operators still functions in the "paper" form.
Problem of this field lies in a manual typing of information to operators' system; it relates to wagons, shipment, locomotives, loading, weighing and delivery wagons for carriage by rail. Sometimes retyping information from paper to an information system of a rail operator causes errors and then it generates mistakes in rail operation on the transport route of shipment. Other great mistakes for example occur in payment for transport.
Proposed RFID technology provides a full automation of collecting, processing and providing the information. The system consists of the following parts:

- **Stationary part** – this part represents an automatic identification of wagons when they enter and leave the railway siding area. In this part a scanning device (gate) in the scanning process is necessary,

- **Mobile part** – identification of wagons which will be run by an operator using a mobile computer connected to a scanning device.

Stationary part is advantageous to be built on great railway sidings that have a high volume of transport, for example near railway weights. Mobile part is advantageous for small railway sidings. This technology is very expensive; therefore we propose these two parts of RFID technology in rail operation.
RFID tags must also consist of two parts. The first part carries permanent information about technical characteristics of rail wagon (number of axes, wagon number and weight...). The second part of the tag is rewritable and there will be information about consignments (weight, number of pieces, ID number, sending and delivery station, and more information that is in the consignment note).
In the Figure 7 there is a schematic representation of automatic data processing of wagon load on the railway siding after the application of RFID technology.

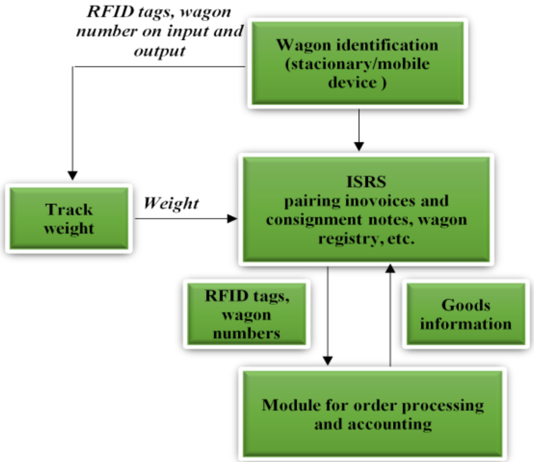


Fig. 7.
Data Processing Scheme of Wagon Load by RFID Technology
Source: (Authors)

A problematic part of RFID technology is its economic side in rail operation. Effective usage of RFID technology requires introducing this technology not only into the whole rail sector, but also to its users. This process is rather expensive despite of its advantages. The Slovak Republic is a transit country from transport flows side and domestic volume of transport is about 14% only. Introduction of RFID technology on Slovak railway sidings doesn't have a significant importance without using it in the international rail transport.

3.2. State Support for Railway Sidings

International and political status of the Slovak Republic creates a pressure on the government and their decisions. Government's decisions must reflect the position of the Slovak Republic as a member of the European Union and reflect their requirements not only for a transport sector. Currently it is necessary to reflect the situation regarding the environment; and rail transport is one possibility how to fulfil ecological requirements.
Transport is one of the greatest air pollutants and it is exposed to a constant pressure under environmental activities. Therefore the European Union passes legislative measures on its protection. White paper, as Gašparík, Abramivič, and Halás said, has an objective to transfer 50% of transported goods from road to environment friendly transport mode till the year 2050. This ambitious aim is impossible without the support of state and governments for railway sidings sector.
State support is possible in several forms. First and easy form is a direct support for infrastructure of railway sidings through the state budget. Maintenance costs of railway sidings are very high and present unprofitable investments for several companies. Through the national infrastructure manager it is possible to unload companies from maintenance costs and achieve a more attractive railway transport. State support must be formed on a non-discriminatory principle and shouldn't restrict competition between transport modes.
Another possible state support for railway sidings operation is through tax credits. For example when companies transport their goods by rail transport they can pay lower taxes to state budget. This solution can solve a great difference between pricing in road and rail transport, as Dolinayová, Daniš and Čamaj said.
Except for the state support having a positive influence on the development of railway siding operation, it is a risk for the state budget. Main means of transport in the Slovak Republic is the road transport. If we decrease income of this mode of transport, it can have a negative impact on the gross domestic product. In chapter 2.3 we showed a very close correlation between transport volume and the gross domestic product. And when transport volume decreases, then the gross domestic product falls, too. Therefore it is important that any changes in the state budget should be undertaken with caution.

3.3. Railway Sidings Connection to Logistics Centres

Slovak economy after transformation made conditions for arrival of foreign investors, who influenced building of logistic centres. The character of logistic centres requires their modality, i.e. their connection to multiple transport modes, but nevertheless in the Slovak Republic such a centre was built without a connection within the railway infrastructure. This fact is caused on one side by costs and on the other side by the fact that the state doesn't have a good national general plan for transport. Therefore we suggest to build a new logistic centre while ensuring its automatic connection to rail infrastructure through railway siding.

The proposal of connecting logistic centres to rail infrastructure is not so costly; it is one form of the state support through legislative measures. The risk of this proposal lies in the loss of a foreign capital since the rail transport has a demanding technology processing of consignment.

Nevertheless this risk factor exists potentially in the intermodal transport. Intermodal transport is growing at a high rate early and then it represents the assumption of a better usage of railway transport in the Slovak transport market.

4. Conclusion

In the past railway sidings served for mining and metallurgical companies; currently they have utilization for different companies. Disadvantageous conditions and a high competition of road transport cause in several cases the reduction of transport volume on railway sidings. Analysis showed a great importance of railway sidings in Slovak rail transport and their gradual disappearance can result in the decline of rail transport in the Slovak Republic. A problematic point is that many railway sidings have an active licence in the operation, but they don't have transport performance. Building new railway sidings is also a negative factor in this challenge, because in the last 25 years too few new railway sidings were built. Liberalisation of rail transport market based on the European Union conditions didn't bring any improvements in this field.

The aim of the paper was to provide proposals for development of railway sidings operation in the Slovak Republic. Based on the calculated correlation the relationship between the gross domestic product and total transport volume was analysed. Next step of analysis was the assessment of the relationship between railway siding and transport volume in rail transport. Both realised analyses showed a great correlation relation and a significant influence of railway sidings on the transport market. Based on the characterised problematics and analyses we proposed three ways for development of railway sidings in the Slovak Republic. Every solution that was proposed has own strengths and weaknesses, but ultimately can lead to a recovery of rail transport in the Slovak Republic.

Acknowledgements

The paper is supported by the VEGA Agency by the Project 1/0095/16 "Assessment of the quality of connections on the transport network as a tool to enhance the competitiveness of public passenger transport system" that is solved at Faculty of Operations and Economics of Transport and Communication, University of Žilina.

References

Abramovič, B.; Brnjac, N.; Škrinjar, J. P. 2014. Railway industrial track as the last mile in supply chain management. In *Proceedings of the Second International Conference on Traffic and Transport Engineering (ICTTE)*, 890-897.

Benko, Ľ.; Reichel J. 2016. Computer analysis of data, basic statistical method, correlation analysis. Available from Internet: <https://amos.ukf.sk/mod/book/view.php?id=8452&chapterid=3191>.

Dolinayová A.; Daniš J.; Čamaj J. 2015. Evaluation of external costs of traffic accident in Slovak Republic, *International journal of social, behavioral, educational, economic, business and industrial engineering*, 9(11): 1-4.

Dolinayová, A.; Ľoch M.; Kanis J. 2015. Modelling the influence of wagon technical parameters on variable costs in rail freight transport, *Research in transportation economics*, 54: 33-40.

Gašparík, J.; Abramovič, B.; Halás, M.: New graphical approach to railway infrastructure capacity analysis, *Promet - Traffic& Transportation: scientific journal on traffic and transportation research*, 4(27): 283-290.

Jurkovič, M.; Dávid, A. 2015. Technological and educational requirements for inland navigation simulator in the Danube region, *Naše more – Our sea: znanstveno-stručni časopis za more i pomorstvo*, 1(62): 13-19.

Kampf R.; Gašparík J.; Kudláčová, N. 2012. Application of different forms of transport in relation to the process of transport user value creation, *Periodica Polytechnica Transportation Engineering*, 2(40): 71-75.

Kejíková, A.; Klapita, V. 2008. *Železničná prepravno prevádzka 2.* Žilinská univerzita v Žiline – EDIS, Žilina, Slovakia.

Ľoch M.; Dolinayová, A. 2015. Evaluation Quality the Freight Transport through Application of Methods Multi-criteria decision. In *Proceedings of the Economics and Finance, International Scientific Conference: Business Economics and Management (BEM2015)*, 210-216.

Lovíšek, M. 2011. Information provision of railway siding operation, dissertation thesis. Žilinská univerzita, Fakulta prevádzky a ekonomiky dopravy a spojov, Žilina, Slovakia.

Palkovič, P. 2016. Regress and correlation analysis. Available from Internet: <http://spu.fem.uniag.sk>.

ŠU SR 2015. *Yearbooks of transport, Posts and telecommunications in 2015*, Statistic office of Slovak Republic Available from Internet: <https://www7.statistics.sk>.

ŽSR 2014. *Case study and survey about the revitalisation of railway sidings on the Slovak railways*, Železnice Slovenskej republiky, Bratislava, Slovakia.

DEVELOPMENT OF THE PUBLIC TENDER OF PATHS ORDERING IN LONG-DISTANCE RAIL TRANSPORT IN THE SLOVAK REPUBLIC

Lumír Pečený[1], Jozef Gašparík[2], Veronika Gáborová[3]
[1,2,3] Department of Railway Transport, Faculty of Operation and Economics of Transport and Communications, University of Zilina, Univerzitná 1, 010 26, Žilina, Slovakia

Abstract: Since the early 1990s, the number of passengers on public transport has declined. One of the reasons is the decrease in population movements in the second half of the 1990s, but a much more serious one is the transition of people from public transport to individual transport. The consequence is that, despite increasing population movement in recent years, the performance of public transport is still declining. Great emphasis is now placed on the quality of services provided by rail passenger transport, which is influenced by several factors. The competition between operators in a public tender when ordering paths in long-distance rail passenger transport is highly significant. The Slovak Republic has made progress in adopting European Union transport policy in separating out transport operators from infrastructure. At present, the Republic has gradually started to apply public tenders to private operators in a liberalised transport market. The aim of this article is to analyse the steps taken by the Slovak government in the announcement of the first public tenders to provide subsidised transport on a selected line and to determine the conditions for this tender.

Keywords: liberalisation of passenger transport, public performance, public tender, Slovak Republic.

1. Introduction

The partial liberalisation of the rail market in the European Union (EU) was already underway in 2010, when all European railway companies with the necessary licences and safety certificates gained access to railway infrastructure in all Member States. However, this only caused the opening up of the market for international rail passenger transport, and did not cover the opening up of domestic rail passenger transport markets in Member States. Currently, there is only a fully open market for rail passenger transport in Sweden and the United Kingdom. In Germany, Austria, Italy, the Czech Republic, and the Netherlands there is a partially open market for new railway undertakings.
One of the current objectives of the common transport policy laid down in The fourth railway package is to open up the market for national rail passenger services in all Member States from 2019, while making public tenders for transport service contracts compulsory, in the public interest.

2. Steps towards liberalisation and the opening up of the rail passenger market in the European Union

A fundamental step in the liberalisation of the rail freight market has been the separation of railway infrastructure managers from railway companies and consequently providing non-discriminatory access to railway infrastructure to the railway companies in all Member States. Opening up the market to new private companies means that several transport companies can compete directly for selected lines at the same time. Given that passenger transport is a State instrument of transport, regional and social policy to provide transport services, it is still largely controlled by the State (Kvizda, M. 2013).
The biggest problem in the opening up of domestic passenger transport is that the tracks upon which traffic is controlled is also subsidised by the State, because it is impossible to create a natural competitive market. The situation has improved because of the impact of European reforms, although the operation of these lines remains costly, so it is not possible to create transparent competition. For this reason, the State continues to control and subsidise traffic performance but the possibility of public competition to secure operations on selected routes followed by their state subsidies is increasingly coming to the fore (Drdla, P. 2014).
On lines with a high volume of operations and a sufficient number of passengers, the situation is more favourable, because railway operators can provide transport services without direct state subsidies, at their own business risk. Competition has thus developed along these lines more slowly but it currently exists on some lines in Member States and they are mainly connecting lines between big towns. In the Slovak Republic, the Bratislava to Košice line is operated this way, as is the Ostrava to Prague line in the neighbouring Czech Republic.
In 2009, the European Parliament and Council Regulation EC No. 1370/2007 came into force, which sets out the selection procedures for the award of contracts in public rail transport. The Slovak Republic's Ministry of Transport, Construction and Regional Development (MDVRR) contracted with the best railway company operating rail services (Železničná spoločnosť Slovensko, a.s., The Railway Company Slovakia Inc., or ZSSK) to carry out transport services in the public interest for a period of nine years (2011 to 2020). This contract also includes operations in regional transport, which are agreed together with operations in long-distance transport.

[1] Corresponding author: lumir.peceny@fpedas.uniza.sk

2.1. The opening up of the market for domestic passenger rail transport services in the Slovak Republic

There are two railway companies with which the State has concluded contracts for transport services in the public interest for domestic passenger transport in the Slovak Republic: ZSSK and the private railway company, RegioJet, Inc. Currently, nine railway companies have a valid licence for the provision of services in public passenger transport. MDVRR commissions regional transport and long-distance transport in the Slovak Republic.
At present, there are two options of providing transport services on the railway infrastructure of the Slovak national infrastructure manager (Železnice Slovenskej Republiky, Railways of the Slovak Republic, or ŽSR). The first is when a railway company provides transport services at its own business risk and this principle is applied to lines with sufficient capacity and performance, where there is less risk of potential financial loss to the company. Currently this type of provision of transport service is used by RegioJet Intercity on the Bratislava to Košice line. The second type is when a railway company provides transport services in the public interest.
Until 2012, the market for domestic passenger transport was virtually closed and all contracts for public transport services were concluded between MDVRR and ZSSK. All ZSSK operations were realised as public transport services and the State reimbursed verifiable losses to the company. This situation changed in 2012 after the entry of a new railway company into the market for passenger rail transport, the RegioJet company, which started operating regional rail passenger transport on the Bratislava to Komarno line on the basis of direct appointment and contracting of transport services in the public interest (Kendra, M.; Masek, J. 2013).
In January 2012, there was a change on the Bratislava to Košice line because of a sufficient number of services and passenger traffic flows. ZSSK started to operate its Intercity trains as commercial trains from a contract on traffic performance in the public interest. For these trains, there is a separate tariff policy, they are not subsidised by the State and the railway company operates at its own business risk. In December 2014, RegioJet started providing the same transport services on the same line, with the result that ZSSK stopped operating its Intercity trains in January 2016.

2.2. Call for public tenders in railway transport in the Slovak Republic

There are two forms of contracts for transport services in the public interest, either by tendering the competition for traffic performance following the end of a contract, or by directly entering the selected railway company. A contract for transport services in the public interest by direct assignment to a railway company was realised on the Bratislava to Komarno line. MDVRR carried out a tender and awarded the transport service to a specific railway company, RegioJet. The contract was agreed in December 2010 for a period of nine years from March 2012 to December 2020 and the contracted transport performance was stipulated at 1.3 million train kilometres (Kendra, M.; Masek, J. 2013).
The analysis by MDVRR showed that, after RegioJet took on the railway passenger transport March 2012, there was visibly increased train traffic on this track (from Dunajska Streda to Bratislava there is a one hour period during the day, and half an hour period during peak time), and as a result there is a significant increase in transport performance.
Year on year, in the period October 2012 to October 2013, there was an increase of 74% in train kilometres, 146% in passenger kilometres, and 115% in the number of passengers of. It was also noted that there was a reduction in the cost per train kilometre of 5.7€, which represents a cost reduction of 16% when compared with a national carrier.
In September 2015, the first competition for subsidised services in the public interest started, when advance notice of invitation to tender for the long-distance Bratislava to Banska Bystrica line was published and, in November, the tender was declared without publication of the estimated value of services. The price of the services, however, is estimated at over 10 million euros. The deadline for this competition was January 2016 and eight candidates enrolled. As at August 2016, the competition had not yet been evaluated (Páteček, P. 2016).

2.3. The long-distance Bratislava to Banska Bystrica line

During 2015, MDVRR began to take steps towards the liberalisation of the long-distance domestic rail passenger service on the Bratislava to Banska Bystrica line, which opened up the market for domestic passenger services to a new railway company. The Bratislava to Banska Bystrica line was chosen because of the provision of sufficient transport performance and passenger flows. The liberalisation process of the Bratislava to Banska Bystrica line is still ongoing, and has entered competitive conditions and criteria stage, although the tender had yet to be concluded in 2015 (Kremensky, P. 2015).
The object of the competition was to ensure safe, effective and quality transport services to passengers between the cities of Bratislava and Banska Bystrica by long-distance trains. The contract for transport services in the public interest will be concluded with an eventual candidate under the Act of Railroad No. 514/2009. Annual transport performance is expected to be in the range of about 1.5 million train kilometres and the extent of transport operations for the year will be specified by a special addition to the contract. For realised traffic performance, the State will reimburse verifiable losses to the railway companies. In 2016, the extent of total transport performance at ZSSK represented 31,304 million train kilometres, thus the competitive amount represents 4.79% of train kilometres operated by ZSSK.
The Ministry declared that one of the objectives of the competition was to generate the most favourable economic conditions for both the State and the passenger, while ensuring the operation of services achieved the required quality. The State currently reimburses around 6.7€ per train kilometre to ZSSK. Provisionally in this contest it envisaged the

inclusion of eight pairs of express trains, which run daily, and two pairs of relief trains running on Friday and Sunday. (Zitrický, Gašparík and Pečený, 2015).
The 2015/16 timetable on the Bratislava to Banska Bystrica line operates nine direct express trains, including eight trains in a two-hour period during the day. Also in the opposite direction there are nine direct express trains, including three trains in the morning one-hour period and the remaining six trains in a two-hour period. The transport has a length of 230 kilometres, achieved travel time is three hours 24 minutes and the average cruising speed is 67.6 kilometres per hour.

2.4. Possible obstacles to the operation of the long-distance Bratislava to Banska Bystrica line

Based on an analysis of the previous steps of the Slovak government in opening up the rail market in the Slovak Republic by process of a competition for a long-distance line, we can define threats and obstacles in two ways: infrastructure assumptions, and operational/technological aspects. To analyse the railway infrastructure which makes up the Bratislava to Banska Bystrica line, we have to evaluate the category and the technical level of infrastructure elements:

- Bratislava to Palárikovo (as part of the corridor lines of Bratislava to Štúrovo)
- Palárikovo to Šurany to Levice to Dúbrava to Zvolen
- Zvolen to Banska Bystrica (as part of the track Zvolen to Banska Bystrica to Diviaky to Vrútky)

Selected technical characteristics of the track sections are shown in Table 1.

Table 1
Technical characteristics of selected track sections

Track	**Track category**	**Number of track lines**	**Maximum track speed [km/h]**	**Train length norm[m]**	**Capacity [trains/day]**
Bratislava – Palarikovo	1	2	140	700	140/140
Palarikovo – Kozarovce	2	1	100	540	86
Kozarovce – Hronska Dubrava – Zvolen	2	1/2	100	540	75
Zvolen – Banska Bystrica	2	1	100	500	105

Source: authors

The Bratislava to Palarikovo track section is a double-track line, included in international pan-European corridors, but this track section has been not modernised. The maximum speed is 140 km/h in the Senec to Sladkovicovo section and 120 km/h for the rest of the track. From Palarikovo, there is a single-track line to Banska Bystrica (except for short double-track sections Zarnovica to Ziar nad Hronom and Hronska Dubrava to Zvolen). A detailed speed profile is shown in Figure 1. The low line speed (maximum 100 km/h, but most of the sections are built only to 80 km/h) and outdated station and track safety devices (without train protection) cause low throughput capacity of the track section, with long time intervals planning trains crossing in the station. In 2014, two passing points were abolished, which reduced the capacity of the lines even more. The result is a low running speed for long-distance trains because of stopping trains for traffic reasons causing delay to other trains (Ľupták and Ponický, 2015).
Finally, the provision of transport process is at a low level as well. There is still only phone security devices, semi-automatic block and all-relay safety devices in some sections, as well as a low level of security at the railway crossing. It should be noted that that route is part of the so-called ‘Southern Corridor of ZSR’, a link between Bratislava and Kosice, the biggest cities in the Slovak Republic.

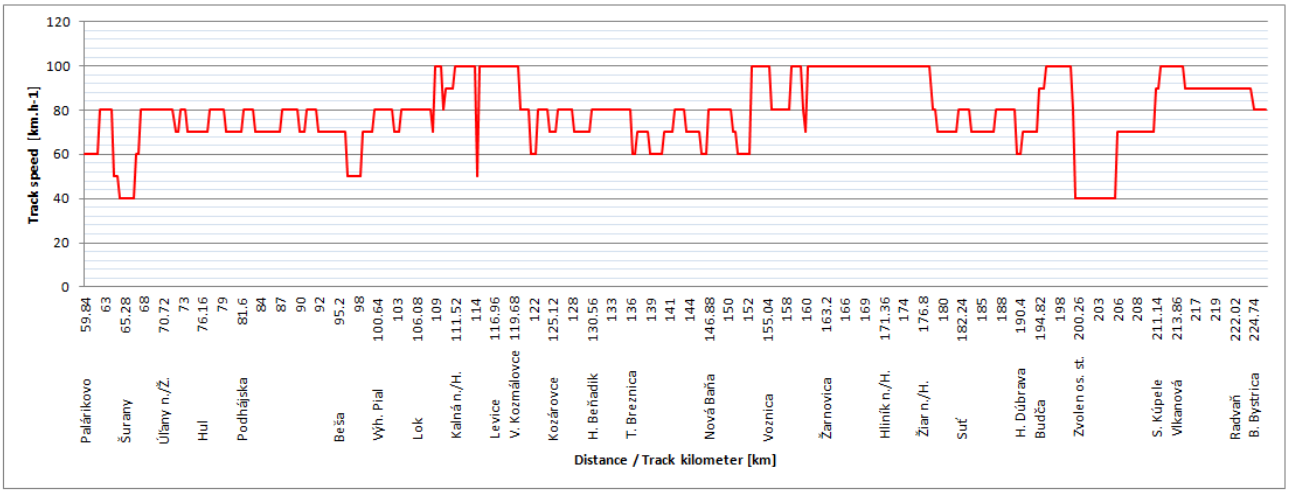


Fig. 1.
Static speed profile of track line Palarikovo to Banska Bystrica
Source: Authors

The opening up of the long-distance rail passenger transport market on lines in bad condition, as has been proven on the Bratislava to Banska Bystrica line, has the following barriers to development:

- limited possibilities for constructing high-quality train traffic diagrams;
- low running speeds;
- difficulties in operational control when there are deviations from the train traffic diagram;
- delays transmitted to other trains when interacting with trains of other railway companies, and
- disputes between railway companies.

In terms of incorporating the long-distance Bratislava to Banska Bystrica line into an open access competition process, the basic problem is the interference with the concept of long-distance passenger transport on the 'southern corridor' as a cut off of the direct fast train Bratislava to Zvolen to Kosice line. This entails creating a separate Bratislava to Banska Bystrica line, with implications for passengers in the form of compulsory transfer at the Zvolen railway station in the direction of Kosice and at the Banska Bystrica railway station in the direction of Zilina. This new concept of operating this line leads to fragmentation tendencies in the rail interconnections network, which can cause a drop in the number of passengers.

The setting of tariff policy and conditions for these trains is also significant, especially in terms of passengers. A problem is the necessity of buying separate travel documents when transferring between state trains and the trains of private railway companies. Difficulties can occur even when setting the connecting links in the Zvolen and Banska Bystrica railway stations between trains of private operators and trains that remain within the competence of the state carrier.

2.5. The proposed framework measures to strengthen competition on the Bratislava to Banska Bystrica line

Framework measures to strengthen free competition on the Bratislava to Banska Bystrica line can be defined within the same structure, i.e., threats and obstacles to infrastructure measurements and operational/technological measurements. Based on an analysis of the current state of the art rail infrastructure, three priority measures have been defined in relation to railway infrastructure:

1. Increasing safety and reliability;
2. Modern and high-quality infrastructure, and
3. Telematics and the support by technical means of ICT.

These priorities correspond to the strategic documents of EU and Slovak Republic transport policy, with respect to rail infrastructure. Improvements in safety should be assessed by the number of railway accidents and their categorisation, and indicators of safety in tunnels and level crossings should also be monitored. The priority of having modern and high quality infrastructure is necessary to eliminate deficiencies related to decline in critical running speeds and capacity deficiencies. The key priority in modernisation is the deployment of telematics applications supported by ICT to achieve a higher quality of traffic management, passenger information and security. Investment in railway infrastructure is a primary prerequisite for the development of competition and providing quality services. Specifically, it is particularly important to promote these infrastructure measures:

- eliminating sections with low running speeds with the general modernisation of permanent ways (a higher level of switches security, eliminating permanent speed restrictions, etc.);
- increasing the capacity of the track section, double-tracking of some overloaded track sections (Zvolen to Banska Bystrica, Levice to Kozarovce), activating cancelled passing points, and building automatic signalling;
- construction of train protection equipment with automatic signalling indications;
- modernisation of level crossing safety devices, including camera systems;

- installation of audiovisual systems for passengers at stations and stops, and
- installation of modern electronic security devices to a central dispatcher station.

Defined infrastructure measures will have a direct impact on the technology of timetabling, shortening travel time and waiting time. It avoids the problem of blame between railway companies due to delays, and railway infrastructure managers will be able to quickly manage the operation of accretion of delays. A particular aspect is the setting of a tariff policy for competing long-distance lines. To maintain the quality of travel and the validity of travel documents, a common tariff policy and tariff conditions must be defined as well as recognition of travel documents for transfer between trains of different railway companies by the order body (MDVRR). Also, when the constructing the train traffic diagram it is necessary to create transfer links (Poliak, Semanova and Varjan, 2014).

3. Conclusion

This is a significant moment in the railway market in the Slovak Republic, preparing the opening up of the market for domestic long-distance passenger rail transport for competition in the provision of transport services in the public interest. This is a comprehensive process that achieves the desired effect only if it is well prepared. This paper identifies two aspects which are essential to ensuring good starting conditions of competition: setting the parameters of the railway infrastructure in terms of capacity and safety performance, and operational and technological aspects, represented by setting a tariff policy and conditions and maintaining connecting links between state and private railway undertakings.

The framework proposal will be able to provide services in a liberalised environment at the required level to meet the needs of the customer, the passenger. The priority, from the perspective of the passenger, is transit time and it should be noted that the line for competition already has a significant competitor in the form of road traffic, with the completion of the highway R1, where travel time is two hours and 50 minutes by bus and two hours and five minutes by car.

Acknowledgements

The paper is supported by the VEGA Agency under Project 1/0095/16 “Assessment of the quality of connections on the transport network as a tool to enhance the competitiveness of public passenger transport systems”, found at the Faculty of Operations and Economics of Transport and Communication, University of Žilina

References

Contracts for the transport services in the public interest in the operation of passenger transport by railways. 2016. Available from Internet: <http://www.telecom.gov.sk/index/index.php?ids=89042>.

Drdla, P. 2014. *Passenger traffic regional and national importance* (in Czech), University of Pardubice, 1, 412 p. ISBN 978-80-7395-787-2.

Kendra, M.; Mašek, J. 2013. Experiences with providing transport services by a private carrier in regional railway transport. Regulated and Unregulated Competition on Rails. In *Proceedings of Telč 2013*, Masarykova Univerzita Munipress, 117-129. ISBN 978-80-210-6425-6.

Kremenský, P. 2015. Railway line to Banska Bystrica attracts Czech and German railway undertakings. Available from Internet: <http://ekonomika.sme.sk/c/7669051/vlakova-linka-do-banskej-bystrice-laka-ceske-a-nemecke-firmy.html>.

Kvizda, M. 2013. Regulation of a competitive environment on railways – time to decide. Regulated and Unregulated Competition on Rails. In *Proceedings of Telč 2013*, Masarykova Univerzita Munipress, 93-116. ISBN 978-80-210-6425-6.

Ľupták, V.; Ponický, J. 2015. The optimization of railway infrastructure capacity between Zvolen and Banska Bystrica: need for creating an integrated transport system (in Slovak), *Railway Transport and Logistics*, 11(1): 15-18. Available from Internet: <http://zdal.uniza.sk/images/zdal/archiv/zdal_2015-01.pdf>.

Notification of Public Tender in the Official Journal č.188/2015. Available from Internet: <https//www.2.uvo.gov.sk/profily/-/profil/zdokumenty/2305/155045>.

Páteček, P. 2016. Competition for fast trains from Bratislava to Banska Bystrica should be repealed. Available from Internet: <http://www.zeleznicne.info/view.php?cisloclanku=2016060010&nazevclanku=komentar-sutaz-na-rychliky-bratislava-%96-banska-bystrica-by-mal-minister-dopravy-zrusit>.

Poliak, M.; Semanova, S.; Varjan, P. 2014. The importance of risk in public passenger transport financing, *Communications: Scientific Letters of the University of Žilina*, 16(2): 92-97. ISSN 1335-4205

Regulation (EC) No 1370/2007 of the European Parliament and of the Council on Public Passenger Transport Services by Rail and by Road. Available from Internet: <http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32007R1370&from=SK>.

Strategic Transport Infrastructure Development Plan of the Slovak Republic to 2020, Ministry of Transport, Construction and Regional Development. Available from Internet: <http://www.telecom.gov.sk/index/index.php?ids=165524>.

Zitrický, V.; Gašparík, J.; Pečený, L. 2015. The methodology of rating quality standards in regional passenger transport, *Transport Problems (Problemy Transportu): International Scientific Journal*, Sp. Edition, 10: 59-72.

ANALYSIS OF THE POSSIBILITIES OF CONSTRUCTION A RAILWAY LINE VAREŠ-BANOVIĆI

Nedžad Branković[1], Smajo Salketić[2], Azra Ferizović[3]
[1,2,3] *Faculty of Traffic and Communications, University of Sarajevo, Sarajevo, Bosnia & Herzegovina*

Abstract: Construction of new railway lines is a significant economic breakthrough and has historical significance. Inconsistent transport policy and marginalizing the significance of railways are the reason of the decades-long stagnation in the expansion of the railway network in Bosnia and Herzegovina. The last major project of regional importance, finalized in 1991, the construction of the Tuzla-Zvornik, which is viewed in a broader context and with more variants. One variant of the construction of the railway Vareš-Banovići and connecting Sarajevo and Belgrade shortest possible rail line. In the context of the new European integration processes, economic developments in B&iH and the region and the projected development of the power sector of Bosnia and Herzegovina, the issue of the construction of the railway Vareš-Banovići takes on a new dimension and over again is updated. The construction of the railway Vareš-Banovići would ensure more efficient binding B&H power sector by rail as the shortest and most economical route. It would, at the same time, mean quality traffic communication between Tuzla and Sarajevo region and reduce travel time to the Port of Ploče for Tuzla economy of over 100 km, and the intense involvement of BiH in Baltic-Adriatic transport flows. The paper emphasize technical-technological and managerial (SWOT) aspects in the function of the sustainability of the railway line Vareš-Banovići project building.

Keywords: railway, power sector, regional integration, SWOT, sustainability.

1. Introducion

The idea of building a railway line Vareš - Banovići and linking Sarajevo and Tuzla in that direction is very old and it is periodically actualized. The first analysis began after World War II, ie. after the construction and putting into operation the railway Brčko-Banovići in 1946. An important step was taken in 1953 when the narrow track railway line Podlugovi –Vareš was abolished and opened newone to traffic lines with normal track gauge on this section. As a logical sequence was the continuing of the construction of the railway line from Banovići to Vareš in order to interrelate these two great mining centers.
Feasibility Study from the seventies has promoted this idea in a wider context: it has been made an analysis of the feasibility of the construction of the railway line Zvornik-Živinice and Banovići-Vareš. According to the aforementioned Study, which examened several variants, the Vareš-Banovići line would be approximately 50 km long passing through mountain ranges Zvijezda and Konjuh.
This involved connecting Bosnia and Herzegovina and Serbia connecting Sarajevo and Belgrade with a new railway route. Analyzes were performed and comparisons in relation to the railway line Tuzla-Doboj-Zenica-Sarajevo. In the end the decision was made to build the Tuzla-Zvornik and finally in 1991 he built the railroad shares Živinice-Zvornik, of a distance of 55 km. This presented the only one direct railway communication with standard gauge of 1435 mm between Sarajevo and Belgrade. The narrow track railway line of 760 mm over the Višegrad was canceled on seventies, and the other two rail lines between Sarajevo and Belgrade (via Vrpolje and Vinkovci) are realized via railways lines in Croatia.
Postwar period of recovering Bosnia and Herzegovina has not appostrofided an idea of construction of Vareš–Banovići railway line as a priority. However, the occasional discussions on expert and political level about the extension of the new railway lines in Bosnia and Herzegovina and conections with the region included, among rest, railway line Vareš–Banovići, as well.
The post-war recovery of railways in Bosnia and Herzegovina was designed in three phases. The first phase involved the establishment of rail traffic on all lines. The second phase is to bring the railways in all segments (infrastructure, mobile capacities, services) on the level of the nineties. In the third phase is planned step forward in technological and organizational terms and one of the goals was the construction of new railway lines including the line Vareš- Banovići.

[1] Corresponding author: info@pin-b.ba

Fig. 1.
New railway lines in Bosnia and Herzegovina
Source: ŽFBH, 2006.

Figure 1 is a proposal for the construction of new railway lines in Bosnia and Herzegovina and the region in June 2006, including the drawn line and Vareš-Banovići.

2. Theses which emphasizes the construction of the railway Vareš-Banovići

2.1. Thesis 1: The strategic effects of linking the electricity sector in Bosnia and Herzegovina

Serious investment in Bosnia and Herzegovina with the support of foreign creditors in the last decade is mainly focused in infrastructure. International banks lend to construction of highways and overhaul and modernization of railways on the main lines. Regarding the other economic resources, foreign investors are only interested in the energy sector, and it is realistic to expect its intensive development in the coming decades[2].
Bosnia and Herzegovina is a manufacturer and exporter of electricity. Currently it has the resources to produce electricity whose installed capacity of about 4,000 MW. The three power utilities in Bosnia and Herzegovina, these resources are distributed according to the Table 1.

Table 1
Energy resources of Bosnia and Herzegovina

Company	Installed power	Structure
Elektroprivreda BiH	1600 MW	of which about 25% of the hydropower
Elektroprivreda RS	1600 MW	of which about 50% of the hydropower
Elektroprivreda HZHB	800 MW	total power from hydropower plants

In terms of production capacity of Elektroprivreda BiH, 25% of the installed power in hydro power plants on the Neretva River, and 75% in thermal power plants Kakanj and Tuzla as follows:

- Thermal power plant Tuzla 4 blocks of 715 MW,
- Thermal Power Plant Kakanj 3 blocks of 450 MW.

According to projected and contracted parameters of two new power plants of Elektroprivreda BiH should provide for about 800 MW of installed capacity, which will increase to 50% more installed capacity, as follows:

- Thermal power plant block VI of 450 MW,
- Thermal power plant Banovići 350 MW.

The aforementioned parameters of the power and importance electric-power sector for the entire economy of country impose certain considerations and emphasize the construction of the railway line Vareš-Banovići. The three thermal power plants of Elektroprivreda BiH (Tuzla, Kakanj and Banovići) with installed capacity of approximately 2,000 MW

[2] It was built power plant Stanari near Doboj. Block VI Power Plant Tuzla is contracted and expected its construction, and regarding the power plant Banovići the international tender has been completed and is expected to select a contractor. All these energy facilities financed and built the companes from China.

are located on the slopes of the mountain Konjuh and Zvijezda of which is done digging coal to generate electricity and that are geographically situated next to each other (divides them only river Krivaja), but these three thermal powers are in terms of communication each other very distant (about 230 km). From the technical and technological, logistic and many other reasons, these three plants should be connected by the shortest possible route. Since the work of these industrial giant unthinkable without quality railway communication it is logical that they should be linked by railway line with upper quality level than it is now. Here bellows are the results of a short analysis of comparison data are unambiguous:

1. Kakanj - Tuzla - Banovići about 230 km (currently, over Doboj),
2. Tuzla - Banovići - Kakanj about 130 km (over Vareš) - 100 km.

Bearing in mind that the current needs of Kakanj and Tuzla rail transports per year about 4 million tons of coal, it is expected that these needs after construction contracted plant (TPP Tuzla block VI and Banovići) increase by additional 3 million tons per year. The above statements, suggesting the need for a complete system connects by quality railway line and the shortest route is the logical lines Vareš-Banovići, which is about 100 km shorter than the existing railway lines via Doboj.

Fig. 2.
Linking electric power sector of Elektroprivreda BiH
Source: Authors

Figure 2 shows the map linking three thermal power plants by railway line Vareš-Banovići. This approach to track construction Vareš-Banovići, arising from the context of investment in the energy sector of Bosnia and Herzegovina, for updating the aforementioned reflection and discussion of the introductory part. In fact, such an important endeavors should gain regional significance because its implementation would offer new standards and opportunities in the field of transport.

2.2. Thesis 2: Strategic regional effects provided by connecting Sarajevo and Belgrade for three hours by train

Starting from the fact that the region of Southeast Europe permanently in the focus of events and discussions in the EU institutions and that in these discussions, generally uses the term reintegration of the Western Balkans, most often raises the issue of communication, the shortest and fastest connections between economic centers and capitals of these states. The idea of the seventies of the shortest a rail link between Belgrade and Sarajevo is partly already implemented by construction of the railway line Tuzla –Zvornik, and marginalised Vareš–Banovići railway line, which rounds off the project. Linking Živinice-Zvornik and Vareš-Banovići rail lines leads to the final goal and rail connections Belgrade - Sarajevo and ideas: “Belgrade-Sarajevo by train for three hours."

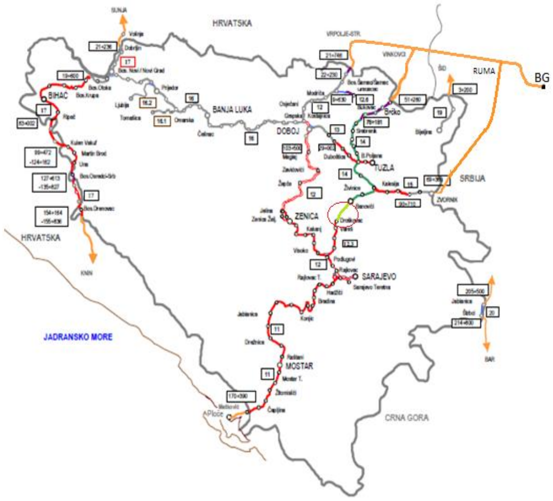


Fig. 3.
Railway network in BiH with connections Sarajevo – Belgrade
Source: ŽFBH, Authors

Very often there are discussions and analysis work on shortened travel time between Sarajevo and Tuzla, two of the largest commercial center in Bosnia and Herzegovina. The existing connnections by road (120 km) and by rail (270 km) are in very bad condition. On several occasions, on this direction were nominated different rail and road route, however shortest distance would be reached by construction of the railway line on the section of Vareš-Banovići. This complex project could become very important when get a regional character connecting Sarajevo-Belgrade by the shortest railway line and then continue to the Port of Ploče on the Adriatic Sea. According to the existing railway network (Figure 3). Currently, from Sarajevo to Tuzla region by rail comes through Doboj. The distances are shown in Table 2:

Table 2
Railway lines linking Sarajevo and Tuzla region

Railway lines	Total length
Sarajevo– Doboj - Tuzla	264 km
Sarajevo – Doboj - Banovići	283 km
Sarajevo – Vareš	53 km

From Sarajevo to Belgrade by train there are three existing railway lines and distances are shown in the following table:

Table 3
The total distance between Sarajevo and Belgrade

Current lines	Total length
Sarajevo – Doboj – Bos.Šamac – Vinkovci – Beograd	500 km
Sarajevo – Doboj – Brčko - Šid – Beograd	571 km
Sarajevo – Doboj – Zvornik – Beograd	524 km

In the case of construction of the new railway Vareš - Banovići, whose length is estimated at about 50 km distance to the railway lines would be shortened in the range of (130-180) km, as it shown in Table below:

Table 4
Estimates of total shortening the distance between Sarajevo and Belgrade

Railway line	km	Comparation	Shorter length for
Sarajevo – Vareš – Banovići	53+50	103 km/ 283km	180 km
Sarajevo – Vareš – Banovići – Tuzla	103+35	138 km/ 264km	126 km
Sarajevo – Vareš – Banovići – Zvornik	103+68	171 km/ 325km	154 km
Sarajevo – Vareš – Banovići – Zvornik – Beograd	171+99	370km/ 524km	154 km

The existing railway line Sarajevo-Tuzla via Doboj of 264 km would be shortened by 126 km and then it was 138 km and the shortest railway line Sarajevo-Belgrade over Doboj and Vinkovci than 500 km would be shortened by 130 km and reduced to 370 km. So, in the case of construction of the new railway Vareš-Banovići, a distance of approximately 50 km defining the shortest distance train for the section Sarajevo-Tuzla 138 km and Sarajevo-Belgrade 370 km. At the present stage of development of technical and technological solutions in the railway transport railway in the world defined as conventional, with speeds up to 160 km/h, and high-speed lines with over 200 km/h. The railway line Vareš-Banovići as part of the line Sarajevo-Belgrade would have the character of conventional tracks and it would be expected that with the repairs and electrification of the entire section it would be reached an average speed of 120 km/h in passenger traffic. Since in the eighties at the time the largest volume of passenger rail transport in BiH, the travel time on the section line Sarajevo-Belgrade were 4.5 to 5 hours, then travel time of three hours would be a new record and the historical success of the two countries and two railways.

2.3. Thesis 3: The strategic effects for the economy of Tuzla region and the respective gravitational area

Such an undertaking automatically entails reducing lines Sarajevo-Tuzla on a little longer than an hour travel time, which would be a historic step forward for the two regions and the whole of Bosnia and Herzegovina, reflecting to the railway line Sarajevo to Ploče[3]. By opening new lines of Banovići to Vareš achieved convergence of Tuzla economy to Sarajevo and Ploče Port for about 130 km. The economy and the population of Sarajevo and Tuzla are very connected to big economic systems in the Tuzla region[4], such as their businesses are based on rail transport through the Port of Ploče.

In the period up to 1992 on Ploče-Sarajevo railway line the freight volumes approximately were 4.5 to 5.0 mill.tonnes of goods per year. In the last 10 years will be transported about 50% of pre-war volumes, meaning approximately 2.2 to 2.5 million tonnes of goods per year. The 50% of all goods transported by rail in this direction, are goods for the economy in the Tuzla region. So that is still on that line for the needs of the economy in the Tuzla region by rail transport from 1.0 to 1.25 mill.tonnes of goods per year, although industrial plants operate with half the capacity. It is expected certainly increasing of the economic development in BiH in the future, and thus increasing the amount of goods transported by train in this direction. With the current parameters, and in the case of shortening the distances listed for about 130 km from Sarajevo to Tuzla, that would mean a saving of 156 mill.ntkm in transport by rail or saving Tuzla economy to transport goods of about 15 mill.KM annually. Return to the previous volume of transport, as the optimal needs of industries in Tuzla region, these values are doubled and the savings would amount to approximately of 30 mill.KM annually.

In the current situation financial parameters are not significant, but must not be ignored new benefits and opportunities in the regional integration that by this railway line could be opened. It is understood that the whole railway line in the length of 370 km were electrified and modernized. It opens up new possibilities for other rail routes that branch off the node Tuzla:

- Railway line Tuzla-Doboj-Banja Luka and further to the west. The overhaul, modernization and electrification of railway line of Zvornik to Ruma via Šabac which has a connection to Corridor X would increase a transport volume capacities and throughput, and would open new opportunities for the economy of the region,
- A new transport route Danube Port of Plčce Port (Danube - Adriatic),
- Shortens the distance railroad Brčko Port - Port of Ploče for approximately 130 km.

If this is the first step towards quality linking Belgrade with Sarajevo and (Tuzla and Sarajevo), then it is surely the second step of addressing mountain pass Ivan and extension to the Port of Ploče, which means connecting port of Brčko and the Danube to the Adriatic Sea by quality rail line through Sarajevo. This entire project would be a great resource of transit goods on Vc Corridor from the Port of Ploče for Hungary and other countries of Central Europe which could be the ultimate goal.

3. Analysis of the possible route of the railway line Vareš-Banovići

There are a number of documents that have dealt with this matter in the past. These are documents that were made for the needs of railways and some national institutions of Bosnia and Herzegovina. The above-mentioned documents offer several variants of the railway route Vareš-Banovići but everyone is a joint that needs to overcome two mountain ranges Konjuh and Zvijezda tunnels from approximately 4 and 8 kilometers in length, respectively. The height difference between Banovići and Vareš is approximately 460 m. Railway station in Vareš is located at 760m above sea level and Banovići at 300m. The route must pass through the valley of the river Krivaja and some of its tributaries and has to connect some places that are in this direction, such as Ribnica, Stjepin Han, Careva Ćuprija, Kamensko, Vijaka and others. In Figures bellow are presented proposed route of railway line Vareš-Banovići, with the longitudinal track profile:

[3] They've already done some studies on shortening the line Sarajevo-Ploče and avoided mountain pass Ivan Sedlo, but it should be the subject of another analysis. In this case calculates with an existing railway line Sarajevo-Ploče, a distance of about 200 km.

[4] (GIKIL Lukavac, Alumina Zvornik, SESCAM SODA Lukavac, Bimal Brčko, etc.)

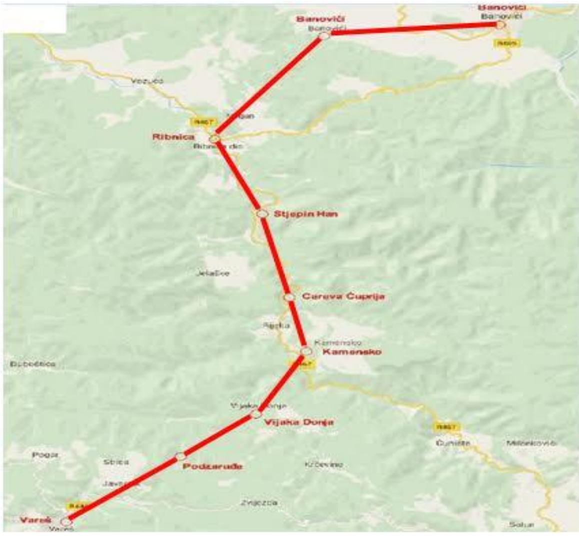


Fig. 4.
Proposed route of railway line Vareš-Banovići
Source: Authors

$$I = \frac{H}{L} = \frac{46.000}{50.000} = 9{,}2‰$$

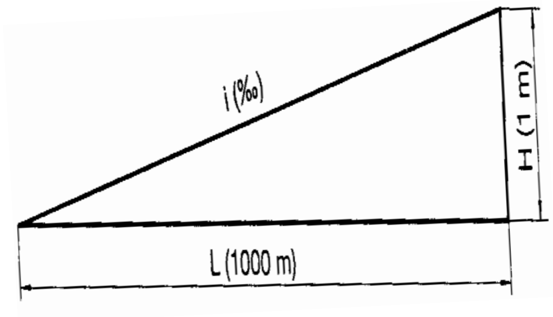


Fig. 5.
Longitudinal profile of track
Source: Authors

What is very important, but it is not subject to these considerations, are the natural, forest and mineral resources regions through which the railroad would passed. From the resources of the mountain Zvijezda for centuries exploited iron ore, followed by lead, zinc, barite, and various kinds of ornamental and building stone. On the slopes of the mountain Konjuh for years digging up coal and other minerals but it is certain that the ranges of these mountains are hidden and other, as yet unexplored mineral wealth enormous value. Forest areas of these regions are among the largest in Bosnia and Herzegovina. Although there are already good quality data on these nature resources, in the event that this project start implementing, it would be necessary to update these information. In the sence of the mobility the construction of this railway line would mean chance the development for people of the related area.

4. SWOT analysis of Vareš-Banovići railway line

Strategic planning of the new railway lines as a part of transport infrastructure should always be a function of the opening: individual mobility, the efficiency of the whole transport sector abd the integration in the transport network of the wider region. Strategic planning of railway network development must be done while respecting the principles of: (1) Burden the state budget, (2) Credited in gross domestic product, and (3) Stimulating effect on the growth of other industries.
The formation of the transport network on the principle of integrity and intermodal respecting subsidiary of conditions for sustainable development by defining the development goals for the dynamic program of infrastructure development with the main content:

- Objectives (strategic and structural),
- Origins (legitimate objectives at the level of international projects, regional level, the European level and the state level),
- The basic elements (valorization of the current situation, the capacity utilization estimate trends in demand),

- The proposal (transport network, traffic-technical characteristics, priorities - the dynamics, the cost of investment, exports),
- The implementation (preparation of project documentation, financing, coordination of relevant departments, responsibility),
- The implementation of the strategic goals of transport development is dependent on the external factors and is sensitive to changes in other economic and governmental departments (SWOT analysis).

Below is a SWOT analysis as a starting point in defining the strategic guidelines for the implementation of the railway line Vareš-Banovići.

Table 5
SWOT analiza projekta željezničke pruge Vareš-Banovići

STRENGHTS	WEAKNEES
▪ Approaching Tuzla and Sarajevo cconomy to the Port area for about 130 km ▪ Shortest rail link between Sarajevo and Belgrade ▪ Mass and variety of transportation ▪ Transit rail route ▪ A high level of safety of transportation ▪ Greater energy efficiency with possibilities the use of national energy resources ▪ Low external costs ▪ Unconditioned climates ▪ Low transport costs ▪ Lacing system te tuzla Banovići- Kakanj	▪ Future railway route in length of about 50 km is very demanding and complicated int erms of construction ▪ It is necessary to build two large tunnels and several very demanding bridges ▪ Fragmentation of infrastructure management ▪ Unsatisfactory level of maintenance capacity ▪ Technological obsolescence of mobile capacity ▪ Lack of management practices ▪ Undeveloped marketing approach and market orientation railways ▪ Accumulated losses and žfbh ▪ Limited new investment projects opportunities ▪ Low productivity
OPPORTUNITIES	**TREATHS**
▪ Intensive integration into regional transport flows and interoperability ▪ Shortening the distance by rail: brčko port - Port of Ploce For approximately 130 km ▪ Opening of a new transport route danube ports - port Ploče (danube - adriatic) ▪ Opening up new opportunities for rail routes Tuzla - Doboj Banja Luka and further to the west and from Zvornik to Ruma via Šabac ▪ Development of the timber industry and mining ▪ Development of tourism ▪ Increasing in gross domestic product in bih ▪ Increased demand on rail traffic market ▪ Creation of mechanisms for sustainable financing of the railway infrastructure ▪ Employment of local labor force and building operations	▪ Inconsistent strategy development of the transport system ▪ Lack of long-term national development strategy for railwa ▪ Insufficient financing of rail infrastructure ▪ Slow implementation of rail investment projects ▪ Unsustainable financial architecture of rail sector ▪ Non-realization of financial consolidation and stabilization ▪ Underdeveloped contemporary models of public-private financing of rail infrastructure ▪ Insufficient attracting foreign investors and the lack of so-called healthy investment climate

Source: Authors

5. Railway line Vareš-Banovići in the European context of meagement of large infrastructure projects

The main Trans-European transport network (TEN-T) objectives are: (1) removing bottlenecks, (2) the construction of the missing cross-border links, (3) promotion of multi-modal integration and interoperability, (4) integration of rail freight corridors, (5) promoting environmentally clean fuel and other innovative transport solutions, (5) the use of modern telematics applications for the efficient use of infrastructure, (6) the integration of urban areas in the TEN-T, and (7) increasing of safety level.

An efficient European transport network is essential to ensure our economic competitiveness. Large infrastructure project are are an important link for European transport and on a higher level contribute to economic and social sustainable growth of our society. Large infrastructure project must be conceived, managed and operated as an integrated whole, focussing not only on the completion of a physical project as an end in itself, but also on stakeholders involved. Key success factor in the organisation and management of large infrastructure projects is a dual focus between 'control' and 'interaction'. Control focuses on the internal world of the project and the project team, requiring adequate (processes for) planning, risk management, financial engineering and scope definition. Interaction is related to the external world of society. Two elements are essential: an open culture and the ability to adapt to changes within the context.

One of the key objectives is to link organisations and stakeholders responsible for developing and introducing new transport inftastructure projects in relation with the new Europena transport policy. This should be done both locally and internationally in Europe for the dissemination of experience and knowledge. The NETLIPSE (2008) has identified five groups of organisations participating in large infrastructure projects:

1. European Commission ,
2. public and private funders, World Bank, European Investment Bank, European Bank for Reconstruction and Development,
3. Project delivery organisations,
4. Parent organisations,
5. Principals / sponsors.

For each of these groups three basic functionalities have been determined. The functionality applies to every organisation but may apply on different levels and with different effects:

1. Project financing order to: judge if a proposed project should be (co-)financed by the EC, national ministries, private funders, World Bank, EIB, EBRD and others,
2. Benchmark, monitoring and project management in order to: (1) monitor the progress of financed projects, (2) evaluate projects (both ex-ante and ex-post), (3) measure the performance of the project delivery organisation with a validated instrument/norm, (4) to enable the comparison of the performance of the project delivery organization to the performance of the project delivery organisations of other large infrastructure projects thereby helping to identify areas for improvement, and (5) to stimulate the successful execution of financed projects,
3. Knowledge management in order to: (1) help to draw experiences – in the form of 'best practices' – from inception through realisation of a project in order to improve the quality of a project delivery organisation; (2) to collect, disseminate and transfer best practises to future project delivery organisations.

Most usual success criteria used assumed that the main criteria for success for projects were the so-called golden triangle of time, finance and required quality. However, the issue of project success turned out to be far more subtle than this. Large investment project management conceptual model developed by NETLIPSE (2008), presented in Figure bellow, links three main aspects:

1. the organisational and managerial factors (project success factors) within the project delivery organization,
2. the project results (critical success criteria), and
3. context of the infrastructure project.

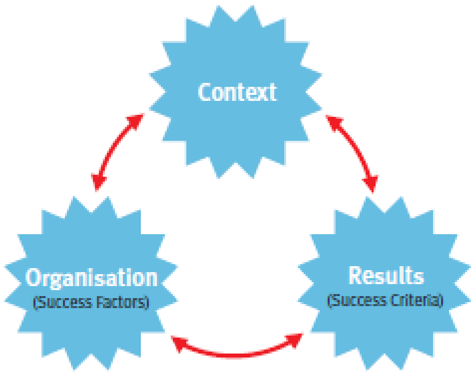


Fig. 6.
Large investment project management conceptual model
Source: NETLIPSE, 2008.

Risk management should also focus on opportunities that often are the result of interaction withstakeholders. The new process uses experiences from former projects to estimatecosts of new projects. With the aid of the Monte Carlo simulation method, best, worst and realistic scenarios can be calculated.

6. Conclusion

The construction of the railway Vareš-Banovići is occasionally actual and very intriguing subject. It offers great opportunities but also opens up a number of issues. Through elaboration is presented to the benefits that it could bring can be viewed from several aspects. First of all it is a binding three thermal power plants from the system EPBIH railway line will be shorter by about 100 km from the present. Then, binding of economy Tuzla and Sarajevo region and the convergence of Tuzla industrial capacity Ploče Port for about 130 km, with the order to make significant savings. It is especially important to note the regional character of the project, approaching Sarajevo and Belgrade for about 150 km, ie, shortening the travel time by train between Sarajevo-Belgrade for three hours.
However, it is clear that the future railway route in length of about 50 km is very demanding and complicated in construction and the execution terms. The height difference between Banovići and Vareš is approximately 460 m. It is

necessary to build two large tunnels and several bridges very demanding. In a time of advanced technologies and high scientific achievements certainly is that these obstacles can be easily overcomed. Also, it should be noted that the available studies, reports and other documents have been made in seventies and that are riped to check and control the application of modern technologies and new technical solutions. There was a change in the overall environment on the railway route. The changed geo-political conditions, because now is the decision of this type largely yields and with the consent of local governments, such as in the present case, Zenica-Doboj and Tuzla Canton. Then, economic conditions (inactivity) on the railway route area dictated by the launch of new investment because some important economic entities have been closed, especially in the municipality of Vareš. In the end, there was a change in the demographic structure of the population, as many as a result of the war displaced. The condition of return and sustainable residue of the region is launching economy activities and employment. The construction of the railway line Vareš-Banovići would represent a significant opportunity for employment of local labor force. In any case, should take advantage of a favorable climate in the EU, where they are now very current issues of reintegration of the Western Balkans and to prepare them for entry into the EU and run this and similar development projects. A large project like this should arouse the interest of relevant stakeholders, encouraged the economy of he whole country and region. Theses presented are actually a step forward to scientific thought in order to provide further scientific support needed for this project.

7. References

Branković, N. 2016. General iteams on strategic planning of transport infrastructure, Faculty of Traffic and Communications-University of Sarajevo.

Džumhur, S. 2007. Željeznice u ptrostornom planu Federacije Bosne i Hercegovine (2008-2028), Stručni rad, (*Railways in the spatial plan of the Federation of Bosnia and Herzegovina* (2008-2028), *Proffesional expertise*).

http://www.elektroprivreda.ba/

http://www.kfbih.co

http://www.opcina-banovici.com.ba/

http://www.vares.info/

Izvještaj o poslovanju Željeznica Federacije BiH za period 2008-2014. Sarajevo, 2014. *(Railways of Federation of BiH Business Report for period 2008-2014. Sarajevo, 2014.).*

Managing Large Infrastructure Projects, Research on Best Practices and Lessons Learnt in Large Infrastructure Projects in Europe, NETLIPSE, 2008.

Preliminarna studija opravdanosti izgradnje pruge Zvornik–Banovići–Vareš, 1970., Biro za studije i projektovanje (IRC) ŽTP Sarajevo, Sarajevo (*The Preliminary Feasibility Study of construction of the railroad Zvornik-Banovići-Vareš, 1970, Bureau of Studies and Design (IRC) ŽTP Sarajevo, Sarajevo).*

Salketić, S.; Šaljić, H. 2006. Elaborat za izgradnju novih pruga u Bosni i Hercegovini, Željeznice Federacije Bosne i Hercegovine, Sarajevo. (*Elaboration on the construction of new railway lines in Bosnia and Herzegovina. Railways of the Federation of Bosnia and Herzegovina,* Sarajevo*).*

Statistički godišnjak o prevozu na prugama JŽ za period 1985-1990. ZJŽ Beograd, 1990. (*Statistical yearbook of transport on the railway lines of JŽ for the period 1985-1990.*, ZJŽ Belgrade, 1990).

SESSION 8: ROAD TRAFFIC AND TRANSPORT RESEARCH - ENVIRONMENTAL PROTECTION AND EFFECTIVENESS

ACIDIFYING EMISSIONS INCREASING DUE TO ROAD TRAFFIC CONGESTION

Eugen Rosca[1], Mihaela Popa[2], Vasile Dragu[3], Dorinela Costescu[4], Aura Rusca[5], Stefan Burciu[6]
[1,2,3,4,5,6] *University Politehnica of Bucharest, Faculty of Transport, Transports, Bucharest, Romania*

Abstract: The road transport sector is one of the greatest contributors to acidifying emissions, especially in NOx emission. Despite the overall reduction trend in the last decade, EU as a whole and other member states failed to meet the emission ceilings set by the EU directive. Due to the harmful potential (acid deposition, eutrophication and human health risk) a special attention is required in transport sensitive areas where the land use individualities, transport network features and spatial/temporal human activities distribution generate specific traffic patterns and often congestion. Following the latest European Environment Agency guidelines, the paper presents a methodology for assessing acidifying emissions by integrating GIS data, road traffic micro-simulation and emission factors. Individual vehicle driving is reproduced and exhaust emissions computed based on average speed, mileage, fuel, engine capacity and standards. The case-study done on Prahova Valley (Carpathians) outlines the way the road congestion influences the emissions at local level, comparing to the Europe average levels.

Keywords: acidifying emissions, traffic congestion, transport sensitive area.

1. Introduction

The Göteborg Protocol under the 1979 Convention on Long-range Transboundary Air Pollution (LRTAP Convention) and the EU Directive on National Emission Ceilings (NECD - 2001/81/EC) set emission ceilings for the acidifying pollutants that states should have met by 2010. The NECD, which is more restrictive, is now part of the implementation of the Thematic Strategy on Air Pollution, and a revised directive should set emission ceilings to be respected by 2020. Within most European Environment Agency (EEA) member states (20 of 32), emissions of the three acidifying pollutants (SO_2, NO_x and NH_3) have decreased significantly between 1990 and 2012 (European Environmental Agency, 2014). The EU-28 met its overall target to reduce emissions of SO_2 and NH3 as specified by the NECD, while just two countries (Finland and Spain) exceeded the ammonia limits. However, based on preliminary data, eleven of the individual member states, and the EU as a whole, missed their NECD 2010 emission ceilings for NOx (European Environmental Agency, 2012a).

Among the economic sectors, the road transport is the main contributor in the total EU-27 nitrogen oxides emission (38.4%), and has lower contribution to ammonia (1.9%) and sulphur dioxide (0.2%) emissions. The NOx exceedance is partially because the sector has grown more than anticipated and partially because vehicle emission standards have not always provided the expected level of NOx reductions.

Although many European states meet their acidifying emission ceilings, a special attention should be paid to transport sensitive areas (e.g. urban and high industrialized areas, mountain corridors, coastal zones). In such areas, the air pollution at local or regional level has negative impact because of high pollutants concentration due to specific climate conditions, canyon effect or atmospheric inversion process which allow the capture of emissions on inferior air layers, soil and water (Whiteman and McKee, 1978; Hobbs, 2000; Wallace and Kanaroglou, 2009; Taseikoa, et al., 2009; Devasthale and Thomas, 2012). Since 2002, NOx average annual mean concentrations at urban background sites have fallen by just 9%, while the reported NOX emissions for the EU-27 decreased by 23% (European Environmental Agency, 2014). Bičárová (2008), Lieb, et al. (2009), Enei and Vendetti (2009), Monigl, et al. (2009), investigate the transport related impacts in different European transport sensitive areas (urban, mountainous or coastal zones). Using macro-scale models, they compare vehicle exhaust emissions in business as usual scenario with scenarios implementing different policy measures (e.g. limited number of crossing heavy-duty vehicles, taxation access, and improved fuel usage). Janic and Jovanović (2012), estimate the positive environmental effects from rail/road substitution in the Trans-European transport corridors.

Acidifying emissions cause damage to ecosystems, human health, buildings, cultural/historical monuments and materials (corrosion). The effects associated with each pollutant depend on its potential to acidify and the properties of the ecosystems and materials. Nitrogen oxides, ammonia and sulphur dioxide contribute to acid deposition and eutrophication which directly disturb soil and water (European Environmental Agency, 2012b). The acid deposition leads to adverse effects on aquatic ecosystems and damage to crops, forests and other vegetation. Nevertheless, the areas subject to acid deposition beyond critical loads in 2010 still exceed 10% of the EEA-32 natural ecosystems. Eutrophication is responsible for decreased biodiversity, changes in species composition and dominance, and toxicity effects. Only in five of the EEA-32 member states the area at risk is estimated to be lower than 50%. NO2 is associated with direct adverse effects on human health, as at high concentrations it can cause inflammation of the airways. Indirectly, the three substances contribute to the formation of secondary particulate aerosols and tropospheric ozone in the atmosphere which have harmful potential. Schwela and Zali (1999), Krzyzanowski, et al. (2005), thoroughly investigate the epidemiological studies of human health effects arising from road traffic air pollution. Pye et al. (2005) and Holland et al. (2011) provide costs-benefits analysis including health and non-health effects generated by the revision of the Göteborg Protocol and the EU Directive on National Emission Ceilings.

[1] Corresponding author: email eugen.rosca@gmail.com

2. Assessing the road traffic acidifying emissions through computer simulation

Across Europe, the most pertinent tools for estimating road transport emission that have been used are CORINAIR (Eggleston et al. 1992), DRIVE (Jost, et al. 1992), COST 319 (Joumard, 2009), HBEFA (Hausberger et al. 2009), TREMOVE (Ceuster et al., 2007), COPERT 4 (Ntziachristos et al., 2009). The European Environment Agency issued the Emission Inventory Guidebook (2009) that covers a high range of exhaust emissions (acidifying substances, greenhouse gases, ozone-precursors, particulate matters, heavy metals, toxic and carcinogenic substances). The guidebook, following the Guidelines for Reporting Emission Data under the Convention on Long-range Transboundary Air Pollution and the EU National Emission Ceilings Directive, provides concise guidance on how to compile an atmospheric emissions inventory at various degrees of sophistication. The EEA guidelines use three approaches, according to the level of data availability:

- Tier 1 approach uses fuel as activity indicator in combination with fuel-specific emission factors, according to the vehicles classification (passenger car – PC, light-duty vehicles – LDV, heavy-duty vehicles – HDV, busses and coaches, motorcycles). The method provides country-specific upper and lower values for all EU nations, but should only be used in the absence of traffic detailed information. It creates a macroscopic view of the emissions inventory,
- Tier 2 approach could be used when vehicle x km statistics per vehicle technology are available. It considers the fuel used by different vehicles categories and their emission standards. The method considers a mesoscopic map of the emission inventory,
- Tier 3 approach calculates exhaust emissions using a combination of technical data (e.g. engine capacity, type of fuel, emission standard) with activity data (mileage and average speed). The detailed Tier 3 approach allows a microscopic view for exhaust emissions and a more accurate evaluation for small areas (e.g. cities, road sectors).

The methodology described in the Emission Inventory Guidebook is now part of the COPERT 4 software – used to calculate air pollutant emissions from road transport in the national emission inventories, and also in CORINAIR – providing date at the county/department level (NUTS level 3).
Using the principles described in EEA guidelines, the following proposed technique for a detailed evaluation of the acidifying emissions combines field recorded data, traffic micro-simulation using VISSIM software and emission factors estimated through Tier 3 approach. The flow chart for the acidifying emissions assessment is depicted in Figure 1.

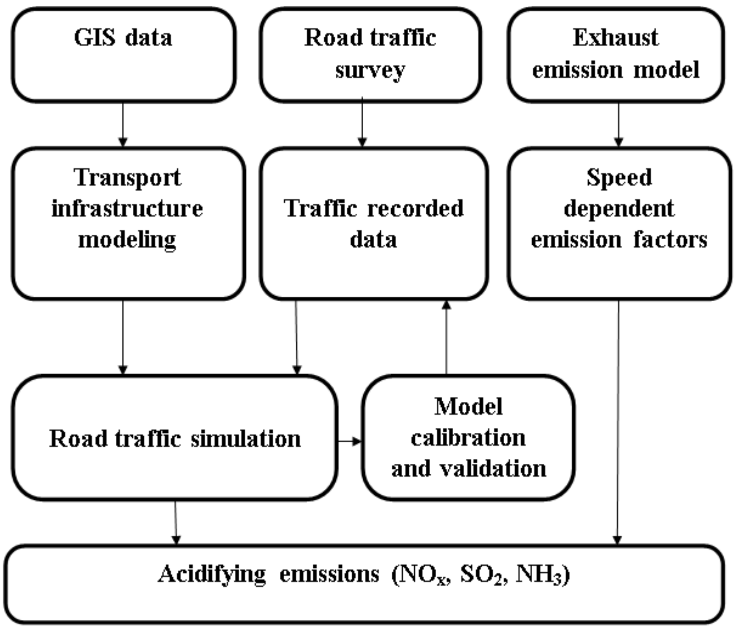


Fig. 1.
Acidifying emissions assessment
Source: original

2.1. Transport infrastructure modeling

The Geographic Information Systems (GIS) provide scalable geographic maps and detailed transport network data used further into traffic simulation programs. Based on real world coordinates, the transport network is modeled in terms of links, lanes, intersections, roundabouts, gradient, public transport terminals/stations, speed limit areas, priority rules, signaling systems.

2.2. Transport infrastructure modeling

The module considers traffic survey data obtained in the field. The vehicles are recorded separately by type (passenger car, LDH, HDV, bus/coach, motorcycle). Traffic flow variations are also observed. The daily peak-hours, weekends or seasonal variations influence the exhaust emissions due to changes in the vehicle driving cycles. The next classification of the vehicles is done according to their fuel type (gasoline, diesel, LPG, CNG, hybrids), technology/standards (pre Euro, Euro 1-5) and engine capacity. Other traffic participants (pedestrians, cyclists) have to be included as long as they interact with the road traffic flows.

2.3. Road traffic simulation

The traffic recorded data and the transport infrastructure model represent inputs for the traffic simulation software. The main advantage when using the computer traffic simulation is to reduce the amount of measurements, which have to be performed in the field. Also the simulation models have the ability to evaluate the future traffic scenarios based on various traffic management schemes. Models describing how to integrate traffic micro-simulation with different emission models are provided in (Xia and Shao, 2005), (Tate, Bell and Liu, 2005), (Boulter and McCrae, 2007), (Panis, Broekx, and Liu, 2006) and (Jayaratne et al., 2009). Traffic simulation allows obtaining the output data that are further used in the exhaust emission assessment:

- The vehicle ID,
- The vehicle type and its technical characteristics (fuel used, engine capacity, emissions standard),
- The mean speed of each vehicle along the route,
- The car mileage of each vehicle.

2.4. Model calibration and validation

The validation process concludes whether the simulation model is close enough to the real system. The validation of the model is usually an iterative process that calibrates the model parameters until the accuracy of the model becomes acceptable (Barceló, 2010) and (Cvitanić, et al 2012). The VISSIM software implements the psycho-physical car-following model developed by Wiedemann (1974). A manual calibration process is used, by varying two parameters describing the car following model:

- Standstill distance (1.0-1.6 m),
- Headway time (0.8-1.2 s).

The validation is achieved by minimizing the mean square between the observed and the simulated mean speed of the vehicles and by computing the GEH statistic that compares the real and the modeled traffic volume:

$$GEH = \sqrt{\frac{2(M-R)^2}{M+R}} \tag{1}$$

Where; *M*: the hourly modeled traffic volume, *R:* the real (counted) one. A *GEH* value less than 5 is considered a good match.

2.5. Emission factors

NO_x and NH_3 are directly estimated, based on the specific emission factors covering different traffic situation and engine characteristics, while SO_2 emissions are estimated based on the fuel consumption.

2.5.1. Nitrogen oxides (NO_x) emission

EEA (2009) offers generic functions for estimating the nitrous oxides emissions in relation to the vehicle type, fuel, engine capacity, engine emission standards and vehicle mean speed. These functions having exponential, power, logarithmical, polynomial form or a combination of them have been estimated through statistical analysis of the empirical data, providing for most of them coefficients of determination higher than 0.85. For instance, the emission factors for Euro 1 and later gasoline passenger cars have the generic function:

$$e_{Euro1,G}^{NOx} = \frac{a + c \times v + e \times v^2}{a + b \times v + d \times v^2} \tag{2}$$

Where; $e_{Euro1,G}^{NOx}$: the NO_x emission factor for gasoline Euro 1vehicles [g/km], v : vehicle mean speed [km/h], $a-e$: calibration coefficients specific to engine capacity.

2.5.2. Sulphur dioxide (SO_2) emission

The SO_2 emission factor is computed based on fuel consumption, assuming that all sulphur in the fuel is transformed completely into dioxide:

$$e_{k,m}^{SO_2} = 2 \times k_{S,m} \times FC_{k,m} \tag{3}$$

Where; $e_{k,m}^{SO_2}$: the SO_2 emission factor for vehicles with engine technology *k* and fuel type *m* [g/km], $k_{S,m}$: weight-related sulphur content in fuel of type *m*, $FC_{k,m}$: fuel consumption [g/km].
The fuel consumption is highly sensitive to the average speed and has different generic function according to the technical characteristics of the vehicles and fuel (EEA, 2009). The weight-related sulphur content is dependent on fuel type and production technology (Table 1).

Table 1
Fuel weight-related sulphur content in Romania

Fuel	Market share	Sulphur content [mg/kg]			
		Min.	Max.	Mean	Limit
Gasoline (95≤RON*<98)	16.45%	4	14	8	10
Gasoline (RON≥98)	10.24%	3	22	8	10
Diesel	73.31%	2	294	12	10

** RON – research octane number*
Source: Romanian Transport Ministry – Fuel Quality Monitoring Report 2010

2.5.3. Ammonia (NH_3) emission

The NH_3 emission factors are calculated according to:

$$e_{k,m,r}^{NH_3} = [a \times Mileage + b] \times EF_{base} \tag{4}$$

Where; $e_{k,m,r}^{NH_3}$: the NH_3 emission factor for vehicles with engine technology *k,* fuel type *m* driving on road type *r* [mg/km], $Mileage$: vehicle mileage [km], EF_{base}: base emission factor [mg/km], *a*, *b*: calibration coefficients.
The average mileages for each country and vehicle category are available on COPERT 4. The NH_3 base emission factors are not strongly dependent on vehicle average speed as NO_x and SO_2 emissions factors are.

2.6. SO_2 equivalence

The acidifying emissions can be aggregated into SO_2 equivalent taking into consideration the potential acidification equivalent (PAE).

Table 2
Potential acidification equivalent (PAE)

Emission	Potential acidification equivalent
Sulphur dioxide SO_2	1
Nitrogen oxides NO_x	0.7
Ammonia NH_3	1.88

Source: Intergovernmental Panel on Climate Change – IPCC

3. Case study. Assessing the acidifying emissions on Prahova Valley

The route along Prahova Valley, situated in the Meridional Carpathians, is one of the most transited routes connecting the southern and the central part of Romania. The route passes alongside the Bucegi Massif that is classified as a type B site (medium influence environment) by the European Network of Protected Areas – Natura 2000. The assessment of the acidifying emissions is done in an area delimited by two important mountain resorts (Sinaia and Bușteni), where due to the transport infrastructure (single lanes, intersections, dense pedestrian crossings) and the traffic non-uniformities, the road congestion often occurs, reducing the level of performance of the network and increasing the car exhaust emissions (Figure 2).

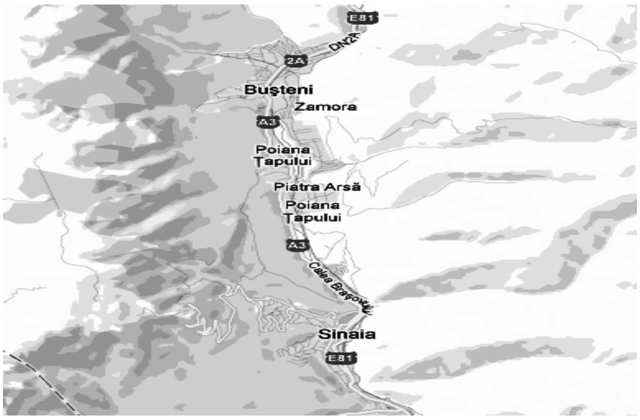


Fig. 2.
Prahova Valley
Source: Google Maps

The GIS transport infrastructure layout is completed by the traffic rules (vehicles speed limit, priority rules in intersections and pedestrian crossings) and by the public transport elements (stations placement, stop times distribution). The traffic flows are recorded separately by vehicles type: passenger car (PC), light-duty vehicle (LDV), heavy-duty vehicle (HDV), bus/coach (BC). The data are differentiated by the weekdays and weekends, outlining the traffic patterns according to the socio-economic activities cycle and the leisure-time travels (Holden, 2007). The average traffic flows (cumulative both ways) are shown in Figure 3.

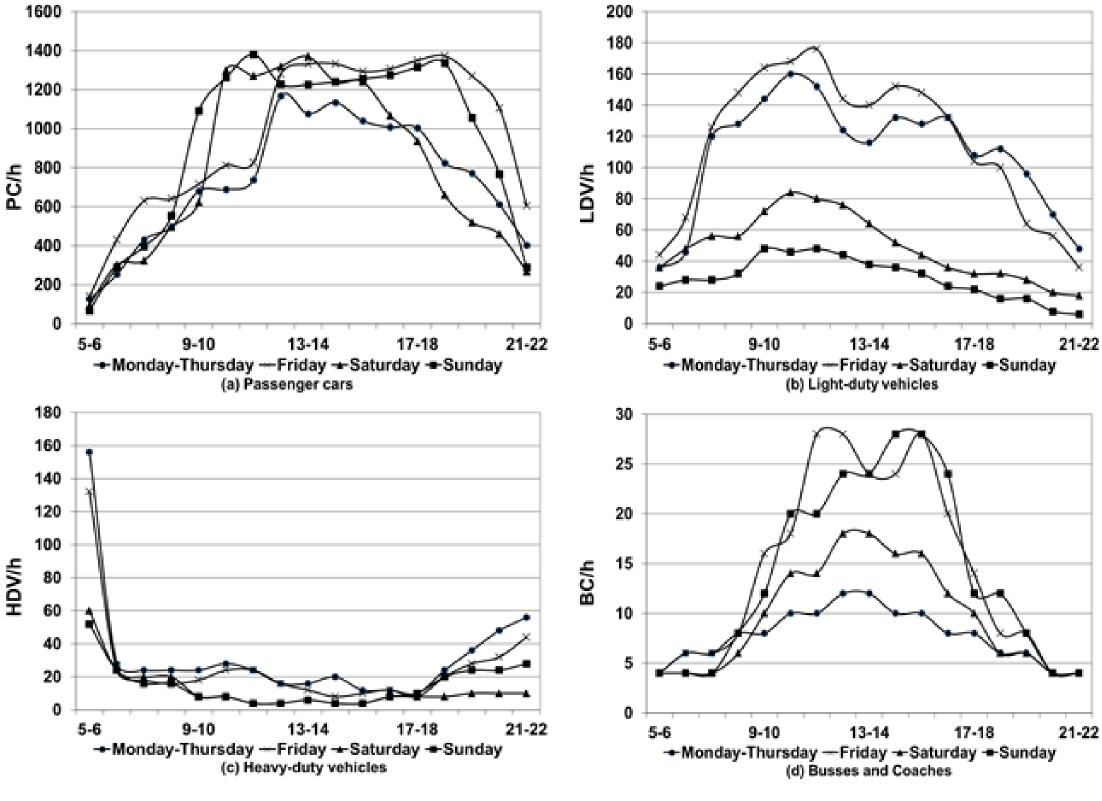


Fig. 3.
Average road traffic flows
Source: Original

The structure of the vehicles flow according to their fuel type and technology/emission standards is shown in Figure 4.

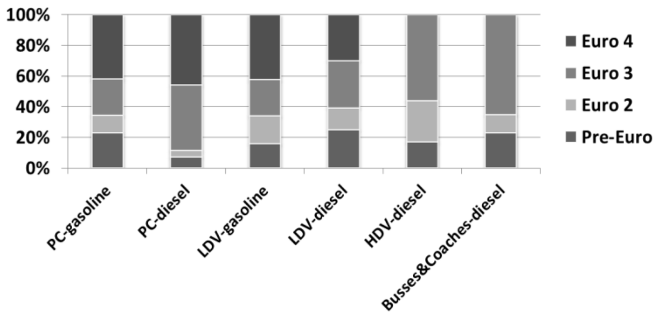


Fig. 4.
Statistical structure of the vehicles flow
Source: Original

The traffic simulation outputs have been obtained by hourly time intervals and by weekdays/weekend. Each vehicle entering the simulation process has allocated individual ID number and characteristics concerning its type, fuel, engine capacity, emissions standard and maximum speed allowed. The plot of the average speed to the traffic flow volume resulting from simulation is shown in Figure 5. The total traffic flow volume is expressed in equivalent passenger car units (PCU) using the equivalent factors proposed by Hobbs (1979).

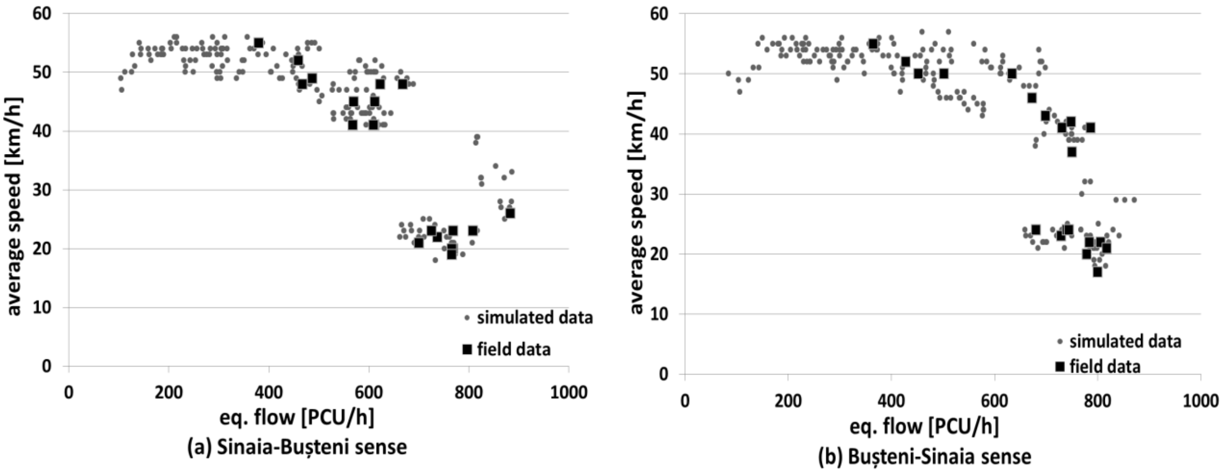


Fig. 5.
Traffic volume vs. average speed
Source: Original

The minimum mean square between the observed and the simulated average speed is obtained for a standstill distance of 1.15m and a headway time of 1.1s. The corresponding GEH statistic takes values between 1.24 and 3.79. The traffic situation creates specific congested phases characterized by a moving synchronized flow pattern that turns during some periods to a moving jam phase. The congestion appears on a single way on Friday and Sunday and on both ways on Saturday.
Following the assessment methodology described in the paragraph 2, the average equivalent SO_2 emission per unit of distance and time and by day of week is depicted in Figure 6.

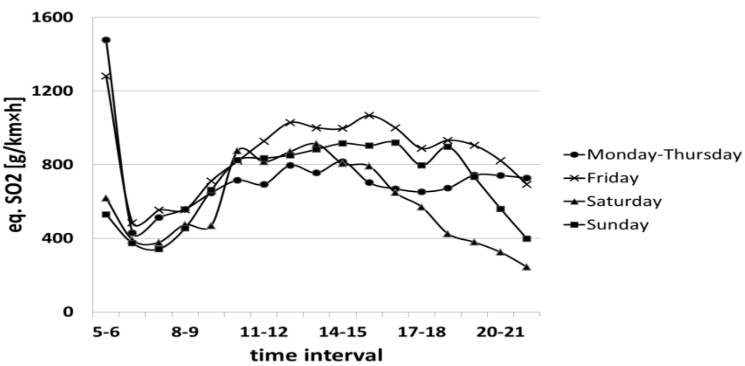


Fig. 6.
Equivalent SO_2 emission
Source: Original

Analyzing the equivalent SO_2 emission in Figure 6, some remarks are issuing:

- The morning emissions are greater during the weekdays due to the heavy-duty vehicles circulation. The HDVs are restricted to circulate on Prahova Valley during 06:00-22:00, unless a special infrastructure access fee is paid,
- The mid-day and the afternoon emissions are highly raised during weekends, due to increase in car traffic volume and the resulting decrease of the speed. As depicted also in Figure 6, congestion occurs during these time intervals of the weekends. The equivalent SO2 emission is 12.8-51.9% higher compared to the same time intervals of the weekdays.
-

The average NO_x emissions for the statistical predominant passenger cars (Euro 4) are depicted in Figure 7.

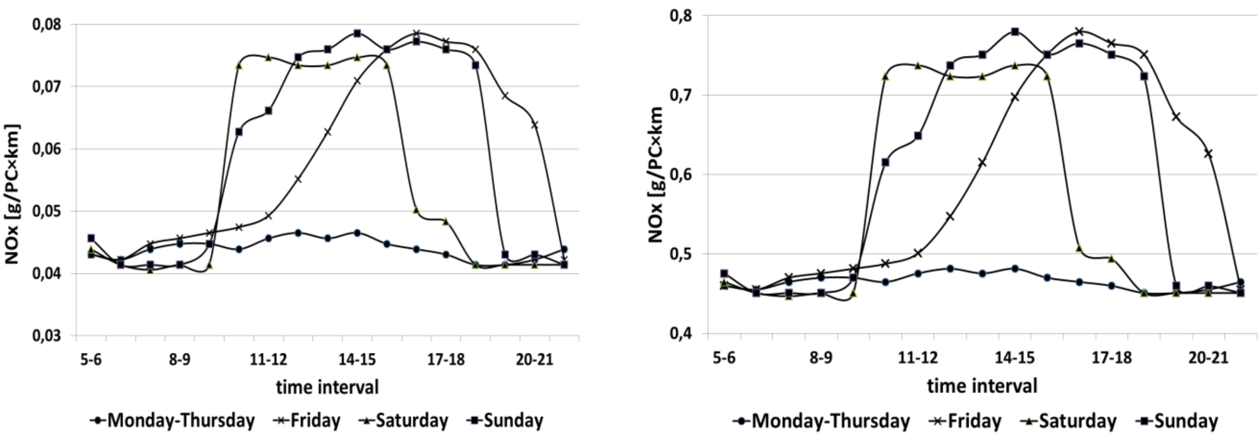


Fig. 7.
Average NO_x emission for Euro 4 passenger cars
Source: Original

During the weekdays and the out-of-peak time intervals of the weekends, the NO_x average emissions for Euro 4 passenger cars are below to the average value recorded at European level – 0.064 g/PCGasoline×km and respectively 0.553 g/PCDiesel×km (2011). This is specific to the free flow or the unconstrained car following flow patterns. During congested periods, the average passenger car emission increases up to 21.7% for gasoline cars and 40.9% for diesel cars.

4. Discussion

The weekend leisure-time and the business tourism are among the most responsible human activities for road traffic congestion and therefore for the growth in vehicle exhaust emissions along Prahova Valley. The rising of car ownership and the land use policies allowing the spread of the residential areas in mountain resorts are translated into an intensive passenger car use in the areas. Most of the new residential areas and the tourist accommodation facilities are developed in zones with feeble or non-existing public transport. At the same time, the modal shift is not well encouraged through national or regional actions towards more efficient transport means. While the main attracted passenger flows come from the great cities in the South region (Bucharest, Ploieşti) or Braşov county, the rail connection among them experience only one intercity train and four express trains/day, but most of them being long-ride trains, are often crowded and not suitable for leisure journeys to Prahova Valley. The decay rail infrastructure and the delay of investments make the journey time excessive by train (at most an average speed of 55km/h by the fastest trains). Due to the rail tickets price, the car journey becomes more attractive at an occupancy rate of 2.5persons/car. The seasonal "snow-trains" can alleviate the problem only on short period during ski season, but the services offered are not at high standards (insufficient space for equipment, poor frequency). No rhythmic train timetable is offered at local level between the mountain resorts. The green consumerism at local level that supports more friendly ways of traveling is also ignored. The decisions of the local authorities regarding the infrastructures do not observe the environmental governance and allowed the spread of the road into the alpine zone and the access of cars up to the hills. No limitations are also for the use of all-terrain vehicles. Developing positive values and green attitudes of individuals are necessary for achieving sustainable mobility in the area.

5. Conclusion

The two European conventions (Alpine and Carpathian Convention) urge for a balance between mobility and environment measures in mountain areas. Integrating transport demand management, market-based measures, land use planning, traffic coordination and education for green attitudes could accomplish this target. The coming into force EuroVignette 2011/76 EU Directive for road transport provides special amendments for transit through mountain areas, allowing the member states to increase the user charges or the tolls rates and to apply double coefficients for computing air and noise pollution. The revenue generated from the mark-up must be invested in transport projects contributing directly to the alleviation of the congestion or environmental damage and which are located in the same corridor as the road section on which the mark-up is applied.

References

Barceló, J. 2010. *Fundamentals of Traffic Simulation*, Springer, New York, U.S.A.

Bičárová, S. 2008. The EU-25 Emissions from Road Transport and Ground Level Ozone Air Pollution at Rural Mountain Sites in Slovakia, *The Open Transportation Journal*, 2: 88-93.

Boulter, P.G.; McCrae, I.S. 2007. *The links between micro-scale traffic, emission and air pollution models*, Transport Research Laboratory, London, UK.

Ceuster, G.D.; van Herbruggen, B.; Ivanova, O.; Carlier, K.; Martino, A.; Fiorello, D. 2007. TREMOVE-Service contract for the further development and application of the transport and environmental TREMOVE model, *Report to European Commission DG Environment*, Transport & Mobility Leuven, Leuven, Belgium.

Cvitanić, D.; Breški, D.; Lovrić, I. 2012. Possibility of Microsimulation Models Calibration-Case Study in the City of Split, *Promet-Traffic&Transportation*, 24(3): 231-241.

Devasthale, A.; Thomas, M.A. 2012. An investigation of statistical link between inversion strength and carbon monoxide over Scandinavia in winter using AIRS data, *Atmospheric Environment*, 56: 109-114.

Eggleston, H.S.; Gaudioso, D.; Gorisson, N.; Joumard, R.; Rijkeboer R.C.; Samaras, Z.; Zierock, K.H. 1992. CORINAIR working group on emission factors for calculating 1990 emissions from road traffic, Vol. 1: Methodology and Emission Factors, *Final Report*, Commission of the European Communities.

Enei, R.; Vendetti, A. 2009. *Assessing Sensitiveness to Transport, WP 5: Mediterranean Case Study, Rome.*

European Environmental Agency 2009. EMEP/EEA Air Pollutant Emission Inventory Guidebook, *Technical Report 9/2009*, Copenhagen.

European Environmental Agency 2012a. *NEC Directive status report 2011*, Technical Report 6.

European Environmental Agency. 2012b. *Exposure of ecosystems to acidification, eutrophication and ozone (CSI 005).*

European Environmental Agency. 2014. *European Union emission inventory report 1990-2012 under the UNECE Convention on Long-range Transboundary Air Pollution*, Technical report 12/2014, Brussels.

Hausberger, S.; Rexeis, M.; Zallinger, M.; Luz, R. 2009. Emission Factors from the Model PHEM for the HBEFA, *Version 3, Report Nr. I-20/2009*, Graz University of Technology, Graz, Austria.

Hobbs, F.D. 1979, *Traffic Planning and Engineering*, Pergamon Press, Oxford, UK.

Hobbs, P.V. 2000. *Introduction to atmospheric chemistry*, Cambridge University Press, UK

Holden, E. 2007. *Achieving Sustainable Mobility-Everyday and Leisure-time Travel in EU*, Ashgate, UK.

Holland, M.; Wagner, A.; Hurley, F.; Miller, B.; Hunt, A. 2011. Cost Benefit Analysis for the Revision of the National Emission Ceilings Directive: Policy Options for revisions to the Gothenburg Protocol to the UNECE Convention on Long-Range Transboundary Air Pollution, *Report to European Commission*, AEA Technology, Oxfordshire, UK.

Janic, M.; Jovanović, T. 2012. Estimating Some Social and Environmental Effects from Rail/Road Substitution in the Trans-European Transport Corridors, *Promet-Traffic&Transportation*, 24(4): 335-341.

Jayaratne, E.R.; Wang, L.; Heuff, D.; Morawska, L.; Ferreira, L. 2009. Increase in particle number emissions from motor vehicles due to interruption of steady traffic flow, *Transportation Research, Part D*, 14: 521-526.

Jost, P.; Hassel, D.; Weber, F.J. 1992. Emission and fuel consumption modeling based on continuous measurements, *DRIVE project V 1053*, TÜV Rheinland, Cologne, Germany.

Joumard, R. 2009. Methods of estimation of atmospheric emissions from transport: European scientist network and scientific state-of-the art, *Action COST 319 Final Report*, INRETS, Paris, France.

Krzyzanowski, M.; Kuna-Dibbert, B.; Schneider, J. 2005 *Health effects of transport related air pollution*, World Health Organization (WHO), Copenhagen, Denmark.

Lieb, C.; Neuenschwander, R.; Scheuchzer, P. 2009. *Assessing Sensitiveness to Transport, WP 5: Case Studies - Alpine Crossing*, ECOPLAN, Bern, Schwizerland.

Monigl, J.; Berki, Z.; Ujhelyi, Z.; Ábel, M.; Székely, A.; Antal, I. 2009. *Assessing Sensitiveness to Transport, WP 5: Budapest Case: Area Access Fee Regime*, TRANSMAN , Budapest, Hungary.

Ntziachristos, L.; Gkatzoflias, D.; Kouridis, C.; Samaras, Z. 2009. COPERT - a European road transport emission inventory model, in *Information Technologies in Environmental Engineering*, Athanasiadis I., Mitkas P., Rizzoli A., Gomez J. (Eds.), Springer, Berlin-Heidelberg: 491-504.

Panis, L.I.; Broekx, S.; Liu, R. 2006. Modelling instantaneous traffic emission and the influence of traffic speed limits, *Science of the Total Environment*, 371: 270-285.

Pye, S.; Holland, M.; Van Regemorter, D.; Wagner, A.; Watkiss, P. 2008. Analysis of the Costs and Benefits of Proposed Revisions to the National Emission Ceilings Directive, *NEC CBA Report 3. National Emission Ceilings for 2020 based on the 2008 Climate & Energy Package*, Report to European Commission DG Environment, AEA Energy & Environment, London.

Schwela, D.; Zali, O. 1999. *Urban traffic pollution*, E & FN Spon, Routledge, London and New York.

Taseikoa, O.V.; Mikhailutaa, S.V.; Pittb, A.; Lezheninc, A.A.; Zakharovd, Y.V. 2009. Air pollution dispersion within urban street canyons, *Atmospheric Environment*, 43(2): 245-252.

Tate, J.E.; Bell, M.C.; Liu, R. 2005. The application of an integrated micro-simulation and instantaneous emission model to study the temporal and spatial variation in vehicular emission at local scale. In *Proceedings of the 14th International Conference Transport and Air Pollution*, 85(1): 138-147.

Wallace, J.; Kanaroglou, P. 2009. The effect of temperature inversions on ground-level nitrogen dioxide (NO2) and fine particulate matter (PM2.5) using temperature profiles from the Atmospheric Infrared Sounder (AIRS), *Science of the Total Environment*, 407: 5085-5095.

Whiteman, C.D.; McKee, T.B. 1978. Airpollution implications of inversion descent in mountain valleys, *Atmospheric Environment*, 12(11): 2151-2158.

Wiedemann, R. 1974. *Simulation des Straßenverkehrsflusses*, Schriftenreihe des Instituts für Verkehrswesen der Universität Karlsruhe, Karlsruhe, Germany.

Xia, L.; Shao, Y. 2005. Modelling of traffic flow and air pollution emission with application to Hong Kong Island, *Environmental Modelling & Software*, 20(9): 1175-1188.

THE INFLUENCE OF DRIVERS' BEHAVIOR AT TRAFFIC LIGHT INTERSECTIONS ON TRAFFIC PARAMETERS AND EMISSIONS

Daniel Kubek[1], Paweł Więcek[2], Dariusz Grzesica[3]
[1,2,3] Institute of Construction and Transportation Engineering & Management, Transport Section, Cracow University of Technology, Cracow, Poland

Abstract: One of the most important issue affecting road safety and reducing the negative impact of vehicles on the environment is identification of the level of emission of harmful compounds into the atmosphere as a result of driver response to events that occur on traffic light intersections. The exhaust emissions will be assigned on the basis of the microscopic traffic simulation model. It uses the driver's reaction time as a parameter related to the drivers behavior. The work will take into account the response time of the move, the response time at a standstill and the response time to traffic lights. The location of the intersection and type of lanes have an impact on the formation of values of these parameters. On the basis of selected conditions the values of emissions of CO2, NOx and PM will be assigned using traffic simulator AIMSUN 8.1. It will also identify the influence of drivers reaction on the traffic parameters.

Keywords: microskopic similation, drivers behaviors, exhaust emission.

1. Introduction

The driver's reaction time is a parameter, directly affecting the safety of road traffic. This parameter can be defined as the period of time counted from the moment the event occurs until the driver can take actions aimed at avoiding the adverse consequences of its occurrence. This is one of the main factors discussed in different road accidents. It is estimated that around 70% of road accidents in Poland is the result of the wrong actions of the driver (Kubek et al., 2014). In this regard, justified is research in the field of driver behavior on the road or intersection.
Actions taken by the driver in traffic situations are characterized by certain individual and various actions which depend on the following factors:

- efficiency of the central nervous system,
- state of mental and physical driver's features,
- situational conditions,
- drivers' experience,
- self-determined action (Bąk and Bąk-Gajda, 2013).

The driver reaction time includes many components, derived directly from him, as well as conditions on the road. They affect the permanent personal characteristics of the driver including age, change the psycho-physical condition, type of road situation, fatigue, biometeorological conditions, noise and alcohol (Stefański, 2008).
A contemporary issue has significant importance to improve road safety and reduce the negative impact of vehicles on the environment is to identify the level of harmful emissions into the atmosphere through the vehicle exhaust. In general it as a result of driver response to events occurring at the intersection. This phenomenon is especially important in Krakow, which belongs to the group of cities with the highest levels of air pollution in Poland and Europe. Except of industry and other of economy sectors the traffic in Krakow, is responsible for a major source of toxic emissions in the atmosphere. These compounds are very dangerous for human health, especially for people living in close proximity to busy traffic arteries. The most dangerous to humans compounds emitted by means of road transport are mainly nitrogen oxides, benzene, carbon, volatile organic compounds (VOC), and also very harmful to your health particulate matter (PM) (Kubek et al., 2014). Mixtures of these contaminants tend to change over time and space, depending on a number of features, such as close proximity of the road, the type and age of the vehicle, traffic patterns, and the presence of other sources of contamination. Short or long term exposure to these compounds in the air, can lead to very adverse health effects immediately or in later years, in the form of the respiratory, nervous and cardiovascular system diseases, as well as cancerous changes. According to measurements made by the WHO vehicles still have a large share in the emission of toxic compounds (Krzyżanowski et al., 2005).
One of the components affecting the emission of harmful substances into the atmosphere is a driver's reaction time at the traffic light intersection. The conducted regression analysis revealed the influence of road traffic factors on the level of driver's reaction time. They reached statistical significance influence level, although the dependent variable was explained in 32% -48% and the key aspects like intersection location, moment of the first car entering the intersection, participation in the movement of heavy vehicles, the position of the intersection and the distance of stop line to traffic light have a great impact (Chodur and Ostrowski, 2012). This study address the issue of harmful compounds emissions in a form of car exhaust as a result of driver response to the traffic light intersection in Krakow. Within the analysis the motion parameters like i.e.: the sum of the intensity of vehicles, average queue length, the sum of the number of stops and average delay were used.

[3] Corresponding author: dgrzesica@pk.edu.pl

2. State of research

The above issues have been the subject of research for many scientists from the country and abroad. The aspect of driver behavior in motion, affects, directly or indirectly, on the level of congestion as well as the level of safety on the road. This is evidenced by the results of the studies presented in numerous scientific research. Foreign authors often classify the study of driver's behavior indicating several subgroups: analysis of the vehicles behavior moving in a convoy, one after another, response of drivers during lane changing, during overtaking maneuver and reactions on traffic light changing at the intersection. In the case of the first three areas, the interesting solutions simulating reaction time and behaviors with the use of artificial neural networks, are presented in the works (Ghaffari et al., 2012; Khodayari et al., 2010; Yan et al., 2015). In addition, the work (Jurecki and Stańczyk, 2011) shows the popular methods of determining the drivers reaction time in the after-crush situations, together with the results of the research.
According to this work, the most crucial and valuable are results and conclusions arising from previous studies regarding to the analysis of the drivers reaction time for traffic light change at the intersection. The analysis of literature shows that studies considering driver behavior at the junction with traffic lights, can be divided into two main groups: studies in the computer simulator and the measurement at intersections (Green, 2000). An important observation arising from the work is the fact that response time reaction to changing light are shorter than those measured in reality. This is due to the simplified visualization, the smaller field of view, shallower depth of space, which have to be dealt with in the simulator. In this area a two situations can be highlighted, in which the driver's reaction time is measured. First is the moment of displaying of yellow light, before the appearance of red light and the second is time respond to a green light appearance. Research referring to the first of the above situations are presented, in particular, in (Goh and Wong, 2004; Rakha et al., 2007). Many works are only focused on the technique of measurement. In study (Guzek et al., 2012), the authors show how to make measurements and collect data using methods of video analysis from cameras installed at the inlet of intersections. There are also a publications, in which the authors take the attempt to create the specific drivers reactions model, taking into account the moment of start braking or the moment when driver decided to start the movement through the stop line (Elmitiny et al. 2010). In (Tang and Nakamura, 2007; Tang and Nakamura, 2008) the impact analysis of traffic signals length on the driver's behavior and time lost at the junction was made. Another interesting aspect shown in (Li et all., 2014) is study of the importance of information about the remaining time before the end of the red signal on the drivers reaction time. The authors demonstrated that the above information for drivers leads to a decrease in reaction time when the green light is transmitted. In addition, the paper presents a highly efficient method for the determination of the mentioned reaction time, based on digital image processing. Regarding to the works of domestic authors the results of complex studies conducted at the crossroads of the city of Krakow were presented in (Chodur and Ostrowski, 2012; Ostrowski, 2011). The research results show that the determinants in the location of the intersection (the urban or suburban road), type of lane (internal, external), etc. play an important role in the calculation of the value of the driver's reaction time parameter.
Summing up the conclusions from the analyzed positions of the literary sources it can be stated that the problem of the drivers reaction for phase change at the intersection with the traffic lights went through many comprehensive studies taking into account numerous aspects and factors. However, a little information and research was found on the impact of driver's reaction time parameter on the emissions level from moving vehicles through the intersection. In relation to the above, it is necessary to conduct a more in-depth analysis and research in this area.

3. Microscopic traffic simulation

Currently noticeable trend in the field of traffic engineering is the application of computer tools to microscopic simulations. Microscopic traffic simulations are used to determine the characteristics of the processes occurring in streams of traffic, and to perform their analysis. Traffic flow and cars motion in simulations are often based on models describing the drivers behavior, for example, the Car following model or the Lane changing model. The traffic simulator Aimsun 8.1 is a computer software whose functionality is allowing to simulate traffic on three levels of detail modeling: micro-, meso - and macroscopic.
In terms of the microscopic, behavior of each vehicles (e.g., selected movement speed) is determined on the basis of the conditions around the vehicle e.g. the way of moving by preceding vehicle, or a vehicle next to it, the status of traffic lights, information provided by traffic signs, as well as congestion occurring on the road. The microscopic simulation in Aimsun software assumes, the movement of the vehicle is calculated according to Car following model or the Lane changing model, developed by P. G. Gipps (Aimsun, 2014). The first model, suggests that the vehicle speed in the *i*-th step of simulation is determined by: readiness of the acceleration to a certain speed parameter, downturn following from local conditions of the vehicle (speed limit, weather conditions) and driver reaction time (Aimsun, 2014). Given the fact that the consideration of this work concern the behavior of drivers, the authors focus their attention on the last element of the model.

4. Drivers reaction time

The one of the basic information in microscopic traffic simulation which has a significant impact on the progress and result of simulation, are the parameters describing the drivers behavior. In the current version of Aimsun, there are three main types of parameters related with driver time response (Aimsun, 2014):

1. Reaction time in traffic - is the response time, what is needed for the driver to adjust their speed to the preceding vehicle,
2. Reaction time at a standstill - the reaction time at the start of the preceding vehicle, which a driver need to start acceleration from a standstill,
3. Reaction time to traffic lights - is the reaction time to green light appearance at the intersection, when a driver is about to start moving.

The first parameter is used in the mentioned Following vehicles Gipps model. This means how fast the driver adjusts their speed to the speed of running ahead of his vehicle. As indicated in (Mehmood and Easa, 2009) reaction time on the resultant motion of two parameters: Acceleration or braking reaction time, marked as RP/Z; the Break-reaction time, marked as RH. Time RP/S is the difference between the receipt of the light signal for the driver to match their speed, and the start of the correction to his speed. Similarly, we can determine the time of RH as the difference between the receipt of the signal stop light the vehicle in front, and at the time of driver response to the signal. In (Jurecki et al., 2012) this time indicated as the psychomotor reaction time during braking, as the time from the onset of the obstacles before the efforts on the brake pedal is defined. In addition, the reaction, the braking reaction time can take on different meanings depending on the situation, for example, if the driver responds to stationary traffic (congestion conditions), normal, or emergency situations.

As follows from the performed reviews, it has no direct studies to determine the values of the reaction time of acceleration/deceleration. For studies that indirectly analyze these phenomena, the one presented in (Chodur and Ostrowski, 2012), all measurements intervals between successive vehicles pass a line stop on the city roads and countryside during the phase of green light were performed. The magnitude of measured time interval may be not enough to describe the time RP/Z. From these studies implies that, depending on weather conditions from the first vehicles to impose certain behavior of other drivers of vehicles queue (Ostrowski, 2011). The average time interval between vehicles on urban roads amounted to 1.87 [sec.], and the standard deviation was 0.18 [sec.]. An interesting phenomenon that was observed in the above studies, it is a gradual reduction of the distance between vehicles in the final phase of the green signal. Additionally was investigated that in Krakow in saturation traffic (e.g., peak traffic) from 8% to 25% of drivers passing on yellow and red signal, which is illegal. Both behaviors significantly affect the security level and the capacity of the intersections.

The second element is the reaction time of the driver in traffic reaction time to braking. If this option was made quite a comprehensive study, presented in (Jurecki and Stańczyk, 2011). Analyses are performed in the driving simulator on a machine in the cockpit of the vehicle using the specialized software, as well as in studies of the landfill that is used for subsequent verification of the simulation. For the sample of 107 participants, aged from 25 years to over 46 years, it was obtained the mean reaction time for braking is in the range of 0.42-0.92 per seconds, and the standard deviation is 0.05 to 0.29 seconds.

5. Selected traffic parameters

Avg Approach Delay: it is calculated as the sum of delay time of each link weighted by the link flow and then divided by the total flow.
Flow: average number of vehicles per hour that have passed through the network during the simulation period. The vehicles are counted when leaving the network via an exit section
Travel Time: average time a vehicle needs to travel one kilometer inside the network. This is the mean of all the single travel times (exit time - entrance time) for every vehicle that has crossed the network, converted into time per kilometre.
Delay Time: average delay time per vehicle per kilometer. This is the difference between the expected travel time (the time it would take to traverse the system under ideal conditions) and the travel time. It is calculated as the average of all vehicles and then converted into time per kilometer.
Stop Time: average time at standstill per vehicle per kilometer.
Number of Stops: average number of stops per vehicle per kilometer.
Mean Queue: average length of the queue in that section, expressed as the number of vehicles per lane. It is calculated as a time average.
Vehicles Waiting to Enter - Number of vehicles waiting to enter the network

Additionally the Aimsun software can model instantaneous pollution emissions caused by acceleration/deceleration and speed for all the vehicles in the simulation based on the paper by Luc Int Panis, Steven Broekx, Ronghui Lui: Modelling instantaneous traffic emission and the influence of traffic speed limits. Each simulation step it measures the emissions for each pollutant using the same formula, but considering different factor values according to the vehicle type, the fuel type and instant acceleration/deceleration measures. In particular, the instantaneous emission model considers Carbon Dioxide (CO_2), Nitrogen Oxides (NO_x), Volatile Organic Compounds (VOC) and Particulate Matter (PM).

6. Simulation results - Case study of Cracow

In the conducted research, the traffic microsimulation of one of the Cracow main arteries (so-called Trzech Wieszczy Avenue) was made. The simulation included the time of morning peak hours and was made based on real traffic volume measurements. In order obtain results indicating how significantly the behavior of drivers affect the emission level, four simulation scenarios have been defined:

– Variant 0 – assumes that actual values of the reaction time (based on the literature review) has been taken to the simulation

– Variant 1 - assumes that drivers follow the traffic laws. It means that drivers do not enter the centre of the intersection when the yellow signal is transmitted at the end of the green phase (late move),

– Variant 2 - assumes that drivers follow the traffic laws, drivers do not enter the centre of the intersection when the yellow signal is transmitted at the beginning of the green phase (early start),

– Variant 1 and 2 assumes that drivers pass through the intersection only when the signal is green.

Based on the above assumptions it was checked what would happen if the driver in Krakow was driving in accordance with the law, and how the behavior of the early start and late passage through the intersection affect the flow parameters and exhaust emissions. The results of this analysis are presented in tables below: for road sections (Table 1), intersections (Table 2) and the whole road network (Table 3).

Table 1

The values of traffic parameters and vehicle emissions, depending on the behavior variants for selected road sections of the road network of Krakow

	Traffic parameter				Pollutant emission		
	Total flow [veh./h]	Mean Queue [veh.]	Number of stops [-/veh./km]	Mean delay time [sec./km]	CO2 [g]	NOx [g]	PM [g]
Variant 0	79 967.00	2.88	57.54	44.06	5 153 006.80	8 212.31	1 258.25
Variant 1	80 800.00	2.93	58.83	53.01	5 197 723,59	8 165,38	1 252.92
Variant 2	76 523.00	3.07	60.51	50.76	5 084 070.03	8 218,08	1 214.11
Variant 1 and 2	79 560.00	3.04	61.22	53.04	5 172 211.14	8 160.08	1 224.85
	Percentage increase/decrease in reference to Variant 0						
Variant 1	-1.04%	-2.03%	-2.24%	-20.30%	-0.87%	0.57%	0.42%
Variant 2	4.31%	-6.91%	-5.17%	-15.20%	1.34%	-0.07%	3.51%
Variant 1 and 2	0.51%	-5.78%	-6.40%	-20.36%	-0.37%	0.64%	2.65%

Source: own elaboration

Table 2

The values of traffic parameters and vehicle emissions, depending on the behavior variants for the intersection of the selected road network of Krakow

	Average Approach Delay [sec.]	Pollutant emission		
		CO2 [g]	NOx [g]	PM [g]
Variant 0	40.61	1 064 432.79	1 546.80	392.46
Variant 1	44.22	1 055 887.12	1 541.04	383.82
Variant 2	45.70	1 031 109.03	1 514.04	379.43
Variant 1 and 2	44.05	1 034 802.58	1 505.90	373.12
	Percentage increase/decrease in reference to Variant 0			
Variant 1	-8.87%	0.80%	0.37%	2.20%
Variant 2	-12.51%	3.13%	2.12%	3.32%
Variant 1 and 2	-8.47%	2.78%	2.64%	4.93%

Source: own elaboration

Table 3
The values of traffic parameters and vehicle emissions, depending on the behavior variants for the selected road network of Krakow

		Percentage increase/decrease in reference to Variant 0		
		Variant 1	**Variant 2**	**Variant 2 and 3**
Traffic parameters	Mean delay time	-3.95%	-4.11%	-8.63%
	Mean flow	-0.02%	4.06%	1.23%
	Mean queue	1.65%	-6.83%	-2.42%
	Mean number of stops	0.00%	0.00%	0.00%
	Mean stop time	-4.71%	-5.07%	-10.43%
	Mean travel time	-3.20%	-3.36%	-6.93%
	Vehicle waiting to enter	-1.49%	-58.51%	-62.99%
Pollutant emission	CO2	-0.58%	1.64%	0.17%
	NOx	0.54%	0.28%	0.96%
	PM	0.85%	3.47%	3.20%

Source: own elaboration

The increase of reaction time on the traffic lights (Variant 2), as well as reducing unauthorized entries into the intersection (Variant 1) resulted in a deterioration of traffic conditions in the analyzed network. This is especially noticeable in average delays at road links and junctions, respectively, the growth even by 20.36% and 12,51%. Despite the fact of realization both the proper behavior of drivers (Variant 1 and 2) the number of vehicles in the analyzed roads is not different from Variant 0, but the capacity of an entire road network decreases (Table 3). This is due to the direct influence of the analyzed reaction time on intersections capacity, which is in this case the main determinant of the capacity of the whole network (Trzech Wieszczy Avenue is one of the most congested roads in Krakow during morning peak hours).
Despite worsening traffic conditions, the values of the estimated emissions have decreased. The best benefits can be achieved for the PM pollution. This is highly relevant information for the analyzed case because the one of the main causes of smog in Krakow is that kind of substance. In the case of implementing both Variants (1 and 2) emission at intersections decreased by almost 5% (Table 2). Additionally it is also very important that, there is no correlation between the increase/decrease traffic parameters and the amount of emissions. For example, increase average delay more than 8% caused a reduction in emissions of NOx and PM more than 3%. This means that reduction of emissions level are not obtained only through a reduced number of vehicles in the network.
In addition, comparing both types of driver behaviour it can be noted that the elimination of the late entry the intersections does not make worse traffic conditions, as the elimination of the early start of the vehicle at intersections . This means that the capacity of intersections is increased mainly by the early start drivers at traffic lights. However, the improvement of traffic parameters causes the expense of emissions - early start generates more emissions of the all considered gases. This is probably associated with a significant increase vehicles fuel consumption, when they performing sudden and sharp acceleration.

7. Conclusions

The drivers behaviors significantly influence and shape the traffic conditions in the cities. Characteristic behavior for the given region (city) can positively or negatively affect the environment. In this example, the illegal behavior of drivers within the intersections have a positive effect on the capacity of intersections. As a consequence of this situation is unfortunately, the increase of exhaust emissions as well as decrease of safety level. Therefore the local authorities should determine priorities of the traffic control to optimize the social and environmental nuisance of road traffic.
Further studies on the influence of driver behavior on the road traffic parameters and value of the emissions will be focused on considering drivers behavior in traffic as well as taking into account other road users other than passenger cars.

References

Aimsun 8 Dynamic Simulator User's Manual, TSS-Transport Simulation Systems 2014.

Bąk, J.; Bąk-Gajda, J. 2013. *Wybrane czynniki psychologiczne wpływające na czas reakcji kierowcy*. Zeszyty Naukowe Instytutu Pojazdów, 5(96): 23 p.

Chodur, J.; Ostrowski, K. 2012. Charakterystyka strumienia ruchu w początkowym okresie sygnału zielonego na skrzyżowaniu z sygnalizacją, *Transport Miejski i Regionalny*, 5: 3-9.

Elmitiny, N.; Yan, X.; Radwan, E.; Russo, C.; Nashar, D. 2010. Classification analysis of driver's stop/go decision and red light running violation, *Accident Analysis and Prevention*, 42(1): 101-111.

Ghaffari, A.; Khodayari, A.; Alimardani, F.; Sadati, H. 2012. MANFIS Based Modeling and Prediction of the Driver-Vehicle Unit Behavior in Overtaking Scenarios, *IEEE International Conference on Vehicle Electronics and Safety*, Istanbul, Turkey. 387-392.

Goh, P.K.; Wong, Y.D. 2004. Driver perception response time during the signal change interval, *Applied Health Economics and Health Policy*, 3(1): 9-15 p.

Green, M. 2000. How long does it take to stop? Methodological analysis of driver perception-brake times, *Transportation Human Factors*, 2(3): 195-216.

Guzek, M.; Lozia, Z.; Zdanowicz, P. 2012. Czas reakcji kierowcy w warunkach awaryjnego hamowania samochodu – badania w symulatorze jazdy samochodem, *Czasopismo Eksploatacja i niezawodność*, Polskie Naukowo-Techniczne Towarzystwo Eksploatacyjne, 14(4): 295.

Jurecki, R.; Stańczyk, T. 2011. Metody badań a czas reakcji kierowców, *Maintenance and Reliability*, 3: 84-91.

Jurecki, R.; Jaśkiewicz, M.; Guzek, M.; Lozia, Z.; Zdanowicz, P. 2012. Driver's reaction time under emergency braking a car – Research in a driving simulator, *Maintenance and Reliability*, 14(4): 295-301.

Khodayari, A.; Ghaffari, A.; Kazemi, R.; Manavizadeh, N. 2010. ANFIS Based Modeling and Prediction Car Following Behavior in Real Traffic Flow Based on Instantaneous Reaction Delay. In *Proceedings of 13th International IEEE Annual Conference on Intelligent Transportation Systems Madeira Island*. 599-604.

Krzyżanowski; Kuna-Dibbert; Schneider. 2005. Health Effects of Transport related Air Pollution, WHO.

Kubek, D.; Więcek, P.; Grzesica, D. 2014. Speed limit evaluation based on pollutant estimation in urban highway: case study in Cracow. In *Proceedings of the Second International Conference on Traffic and Transport Engineering ICTTE*, November 27-28. Belgrade. 517 p.

Li, Z.; Zhang, J.; Rong, J.; Ma, J.; Guo, Z. 2014. Measurement and comparative analysis of driver's perception–reaction time to green phase at the intersections with and without a countdown timer, *Transportation Research Part F*, 22: 50-62.

Mehmood, A.; Easa, S.M. 2009. Modeling Reaction Time in Car-Following Behavior Based on Human Factors, *International Journal of Engineering and Applied Sciences*, 5(2).

Ostrowski, K. 2011. Analiza zachowań kierujących pojazdami w stanach nasycenia ruchem na wlotach skrzyżowań z sygnalizacją świetlną, *Czasopismo Logistyka*. no 3.

Rakha, H.; EI-Shawarby, I.; Setti, J. 2007. Characterizing driver behavior on signalized intersection approaches at the onset of a yellow-phase trigger. In *Proceedings of IEEE Transactions on ITS*, 8(4): 630-640.

Stefański, R.A. 2008. *Prawo o ruchu drogowym – komentarz*. Third edition. Wolters Kluwer Business, Warszawa. 228 p.

Tang, K.; Nakamura, H. 2007. A comparative study on traffic characteristics and driver behavior at signalized intersections in Germany and Japan, *Journal of the Eastern Asia Society for Transportation Studies*, 7: 2470-2485.

Tang, K.; Nakamura, H. 2008. Operational performance of group-based signal control policy under various traffic conditions. In *Proceedings of the 10th international conference on applications of advanced technologies in transportation*, Athens, May. 27-31.

Yan, F.; Weber, L.; Luedtke, A. 2015. Classifying Driver's Uncertainty about the Distance Gap at Lane Changing for Developing Trustworthy Assistance Systems, *Intelligent Vehicles Symposium (IV), IEEE*. 1276-1281.

THEORETICAL ANALYSIS OF THE EFFECT OF DIFFERENT SPEED DISTRIBUTIONS ON VEHICLES EMISSION ESTIMATION

Mohammad Maghrour Zefreh[1], Adam Torok[2]
[1,2] BME – Budapest University of Technology and Economics, Department of Transport Technology and Economics, Budapest, Hungary

Abstract: Vehicles speed distribution is an important input parameter in lots of issues, such as kinematical traffic simulation model, road design, speed limit evaluation, road traffic noise prediction as well as vehicles emission estimation. In this paper, a new approach has been presented in which the speed is randomly generated according to different unimodal speed distributions, and then these speed distributions have been disaggregated using Monte Carlo Method to assign the speed to each and every vehicle. These different distributions are chosen according to the contextual traffic situation (free flow, pulsed accelerated flow, intersection, congestion, etc.). The effect of these different speed distributions on vehicles emission has been surveyed using speed related emission models in a theoretical path. The study of the influence of different distributions on the resulting emission level has been performed. This result leads to the chance in revising the simulation software in further studies by extending these results in bimodal speed distributions and their related emission models. The considerable difference in the emission models related to Log-normal distribution as well as exponential, chi-square and equal distribution to normal Gaussian distribution implies that these different traffic conditions will have a considerable effect on emission even in the unimodal traffic conditions.

Keywords: speed distribution, Monte Carlo method, speed related emission models.

1. Introduction

Data on speeds and travel times of motor vehicles are essential to traffic engineers responsible for design and operation (Berry et al. 1951). Speed is the fundamental measure of traffic performance of a road transport. It indicates the quality of service experienced by the users. Many researchers have put effort for modelling speed either for the homogeneous or mixed traffic conditions (McLean 1978), (Katti et al. 1988), (Shankar and Mannering 1998), (Dixon et al. 1999), (McFadden et al. 2001), (Figueroa and Tarko 2004), (Ali et al. 2007), (Himes and Donnell 2010), (Munawar 2011), (Dhamaniya and Satish 2013), (Tettamanti et al. 2015), (Rao and Rao, 2015). The development of mathematical tools focused on the modelling of the speed distribution in a traffic flow is widely reported in the scientific literature (Castro et al. 2008), (Dey et al. 2006), (Fitzpatrick et al. 2000), (Trozzi et al. 1996). Many papers concern this problem since vehicles speed distribution is an important input parameter in lots of issues, such as kinematical traffic simulation model, road design, speed limit evaluation, road traffic noise prediction, traffic safety evaluation, bicycle performance evaluation, analysis of pedestrian walking (Iannone et al. 2013), (Berry et al. 1951), (Lin et al. 2008), (Wang et al. 2015), (Vadeby and Forsman 2014), (Maurya et al. 2015), (Hustim and Fujimoto 2012), (Aly et al. 2012), (Chandra and Bharti 2013) etc. Since 1940 majority of papers considered speed distribution as Gaussian or Normal distribution (Loutzenheiser and Greenshields 1940) and only extreme situations are considered as the traffic volume exceeds the practical road capacity, the speed distribution may become so heavily skewed toward the higher speeds that all semblance of normality is lost. Modern traffic simulation softwares are also using Gaussian normal distribution for traffic speed estimation and also have built-in emission estimation models (Batterman et. al. 2010). Therefore, the connection between the distribution of speeds and emission is of great importance in this case. Around the world road traffic is the dominant anthropogenic source of air pollution in urban areas (Fenger 1999). Several cities in Europe are facing traffic congestion problem daily in a critical level. Traffic congestion is known to exacerbate emissions from mobile sources in urban areas, thus contributing to air quality deterioration with significant health, environmental and economic impacts (Smit et al. 2008). Emission tests on modern cars with advanced emission control systems (DoTRS 2001) have demonstrated that their emissions are particularly sensitive to the occurrence of congestion in the driving cycle. In this situation, the motor vehicles such as passenger cars and motorcycles have made zigzag maneuvers disturbing the travel speed (Maghrour Zefreh et al. 2015) and behaviours that are insufficient for the mentioned traffic condition. Therefore, the motor vehicles behaviour may change from homogeneous situations to heterogeneous conditions. The remainder of this paper is organized as follows: Section 2 describes how the methodology processed in order to disaggregate different velocity distributions and then estimates their related emission. Section 3 presents the results and the outputs of different velocity distributions and emission distributions. Section 4 compares speed related emission distributions with normal Gaussian distribution. Finally, Section 5 summarizes the conclusions.

2. Methodology

As suggested in literature, speed distribution models might be useful in the development of traffic simulation model for vehicle emission and traffic noise predictions (Hustim and Isran 2013). For comparing the effect of different speed distributions on emission estimation, a theoretical path has been investigated in this research. The average speed, number of vehicles and the speed distribution are given as an assumption. It should be underlined that the number of vehicles, their average speed, and travel distance are remain constant in all cases. The emission is estimated based on

[1] Corresponding author: mohammad.maghrour@mail.bme.hu

different speed distributions using the so-called speed based emission models. Speed based emission models, like MOBILE (USEPA 2007), EMFAC (CARB 2002), COPERT (EEA 2000) and others (e.g. Namdeo et al. 2002), are regularly applied in practice. In these models, emission factors (g km1) are stated as a function of average speed. Traffic situation models use discrete emission factors (g km1) for certain traffic situations, which can be defined in terms of a textual description (e.g. INFRAS 2007) or by a set of quantitative variables (e.g. TNO 2001). In the present research, first the random speeds were generated by determining the discrete probability variable based on different distributions according to different traffic conditions (discussed later). Then the speed distributions were disaggregated using Monte Carlo method after programming the macro environment of the MS excel software. With this method, based on the distribution individual speed could be assigned to each vehicle. This process has been shown in Fig. 1.

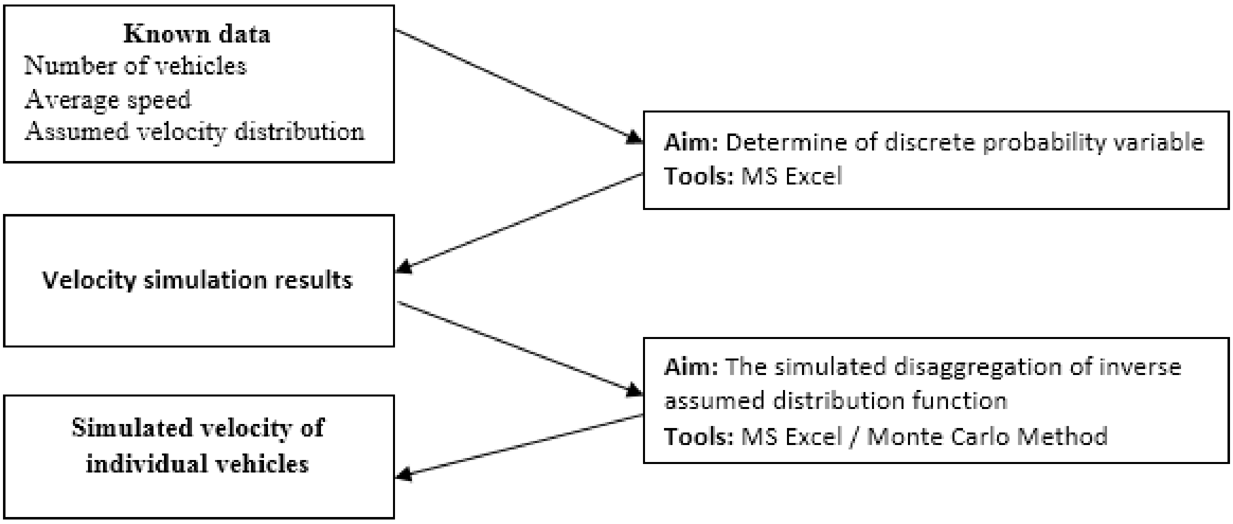


Fig. 1.
Simulation Process

Monte-Carlo methods (or Monte-Carlo simulations) are computational algorithms that rely on repeated random sampling (Torok 2015). Typically simulations run many times in order to obtain the distribution of an unknown probabilistic parameter. Monte Carlo methods are mainly used in three distinct problem classes: optimization, numerical integration, and generating draws from a probability distribution (Kroese et al. 2014). It provides a powerful computational framework for spatial analysis and has been used to disaggregate data in areal units to individual points (Hu and Wang 2015). For example, Watanatada and Ben-Akiva (1979) used it to simulate representative individuals distributed in an urban area for travel demand analysis. Wegener (1985) designed a Monte Carlo based housing market model to analyse location decisions of industry and households and corresponding migration and travel patterns. Gao et al. (2013) applied it to simulate resident and business distributions proportionally to mobile phone Erlang values and to predict traffic flow in a road network. Basically, the Monte Carlo method generates suitable random numbers of parameters or inputs to explore the behaviour of a complex system or process. The random numbers generated follow a certain probability distribution function (PDF) that describes the occurrence probability of an event. The detailed velocity disaggregation flow chart using Monte Carlo method is shown in Fig. 2.

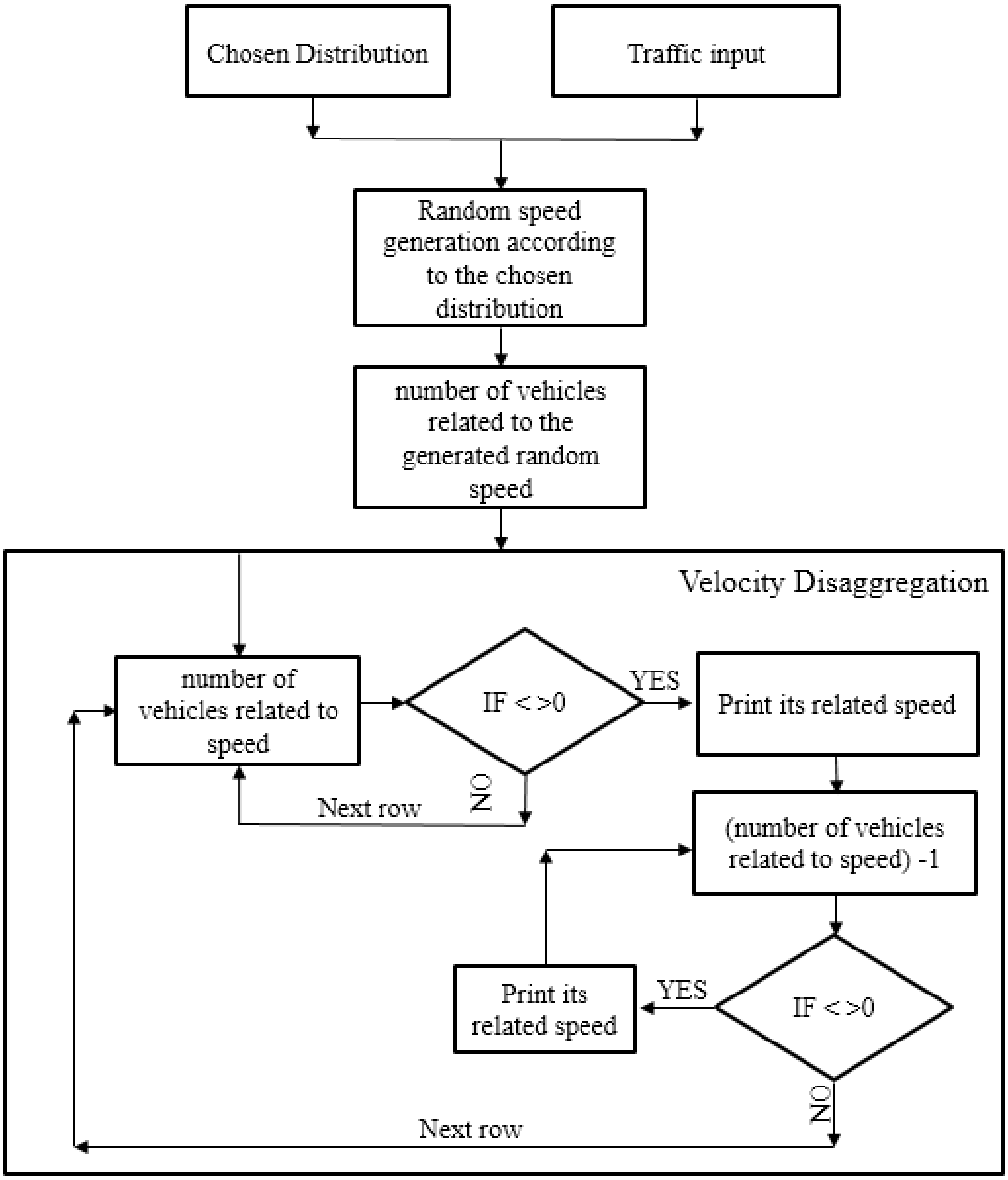


Fig. 2.
Detailed Flow Chart of Velocity Disaggregation

In this paper, the authors focus on the different probability distributions that can be chosen for vehicles speed, depending on the traffic flow conditions. The main aim of this paper is to survey on speed related emission models based on different speed distribution in a theoretical path. These different speed distributions based on different traffic conditions are shown in Fig. 3. If the traffic conditions are not homogeneous, the normal distribution is not well suitable anymore. There is a lot of research that has examined distribution models for motorized vehicle speed data, such as normal distribution, skewed distribution, and composite distribution. In regard to normal distribution, Leong (1968) and McLean (1978) found that, for lightly trafficked two-lane roads where most vehicles are traveling freely, car speeds measured in time are approximately normally distributed with a coefficient of variation ranging from about 0.11–0.18. Minh et al. (2005) have studied that the speed distribution followed the normal distribution on the urban road. Wang et al. (2012) introduced truncated normal and lognormal distribution for modeling speeds and travel time. Yajie Zou (2013) proposed that skew-t distribution can reasonably take into account the heterogeneity in vehicle speed data. Zou and Zhang (2011) said that a single normal distribution cannot accurately accommodate the excess kurtosis present in the speed distribution and they proposed skew-normal and skew-t distribution to fit speed data. They suggested that these two distributions can be applied effectively for both homogeneous and heterogeneous traffic. Haight and Mosher (1962), considered that the speed data could be well represented by either a gamma or a log-normal distribution. Gerlough and Huber (1975) proposed the use of the log-normal distribution. This resembles the normal distribution but is skewed with a larger tail to the right. These distributions offer the advantage that the same functional form is retained when the time speed distribution is transformed into a space-speed distribution and avoid the theoretical difficulty of the negative speeds given by the infinite tails of the normal distribution. Iannone et al. (2013) assumed that a reasonable choice for the pulsed accelerated flow is the Beta distribution while the Chi-Square is proposed for the decelerated flow simulation. This assumption is supported by Harmonoise (2004), where different speed distributions are related to different traffic situations. The conditions that turn to a different speed distribution are quite often realized in non-highway or urban roads, where, in general, the traffic stream is much more complicated. This assumption is supported by (Török and Maghrour Zefreh 2016), where there is a need for applying multimodal speed distribution in road transport emission estimation when the traffic stream is complicated. This large spread of typologies, together with other parameters such as the presence of traffic lights and the road surface conditions, leads to a significant deviation of the speed distribution curve from the generally accepted single modal normal distribution (Iannone et al. 2013). Jun (2010) investigated traffic congestion trends by speed patterns during holiday travel periods using the normal mixture model. He suggested, during heavy congestion speed data shows bimodality which cannot be represented by a single distribution, two different Gaussian mixture model will be required, one mixture component representing low-speed regime and another for high speed. Overall some roadway sections may have more than two modes, e.g., uncongested speed range, interim speed range which lies between uncongested and congested conditions, and congested speed range. The change between unimodal speed distribution and bimodal speed distribution will indicate the pattern of traffic variations of specific interstate freeway systems (Ko and Guensler 2005). In this paper different unimodal speed distributions according to different traffic conditions (congested condition or uncongested condition) have been assumed as a dominant condition and mixed traffic conditions have not been investigated due to the limitation of bimodality distribution in our statistical software MS Excel.

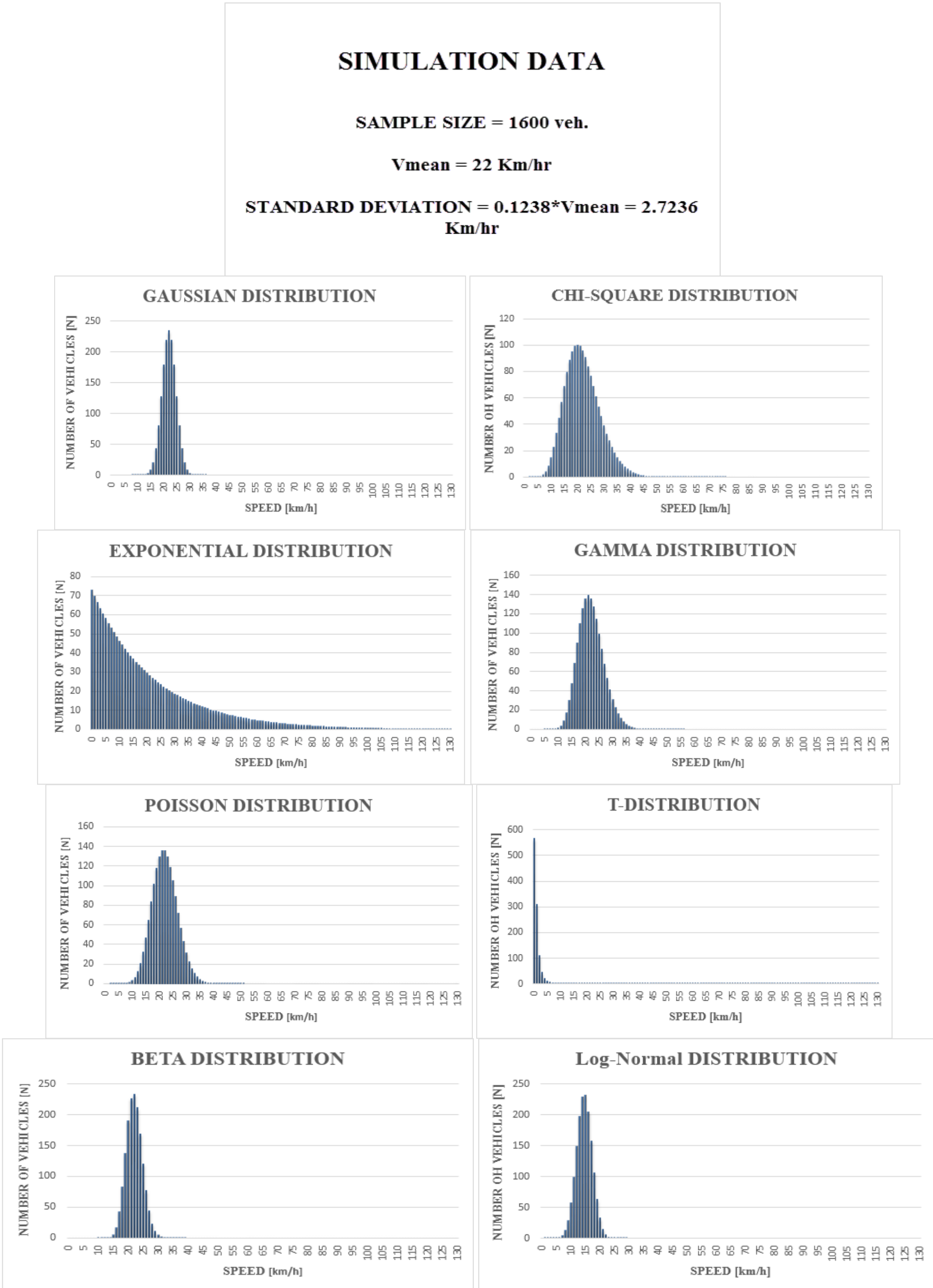


Fig. 3.
Random Speed Generation According to Different Distributions Based on Different Traffic Conditions

After generating random speeds based on the chosen distribution, these speeds were disaggregated using Monte Carlo Method to assign the speeds to each and every vehicle. These disaggregated speeds were used to build emission models related to these speed distributions. The environmental impact of road transport is a relevant issue in the framework of urban settlements since the traffic affect human being health, especially concerning air pollution. Road transport related emission estimating models started to be developed more than 50 years ago and they often show satisfactory results. The main inputs of these kinds of models were traffic flow for each category of vehicles, specific fuel consumption and vehicle speed. Moreover, many models have been developed around the world considering more and more parameters related to road transport specialities of different countries. All these models started from a statistical approach to the emission estimation that generally does not take into account any terms regarding speed distribution only constant fuel consumption. More recent models, starting from a more precise classification into several categories (basically in Europe the EURO environmental emission categories are considered), improve the accuracy of predictions. Nowadays one of the most important development that should be considered is the dependence from the speed. Of course, one could think to overcome this problem by performing a measurement campaign (huge investment and huge effort), but the development of a new model, based on a microscopic approach with laboratory tests, able to describe every kind of traffic condition, results to be an interesting challenge. For this purpose, the Euro II gasoline passenger car with the engine capacity of 1.4-2.0 litre have been chosen for better comparability. Based on the European Environmental Agency Emission Inventory Guidebook (Ntziachristos, Samaras, 2012) the fuel consumption based CO2 emission can be polynomial estimated as a generic function between 10 and 130 km/h (1):

$$\varepsilon_{CO_2}[g_{CO_2}] = \frac{(3.47 \cdot 10^2 + 2.73 \cdot v + 4.28 \cdot 10^{-3} \cdot v^2)}{(1 + 2.71 \cdot 10^{-1} \cdot v - 9.11 \cdot 10^{-4} \cdot v^2)} [g_{fuel}/km] \cdot 3.088 \left[\frac{gCO_2}{g_{fuel}}\right] \cdot 1[km] \qquad (1)$$

3. Results

After generating the random speeds based on different speed distributions, the generated speeds have been disaggregated using Monte Carlo Method. Their distributions have been shown in Fig. 4.

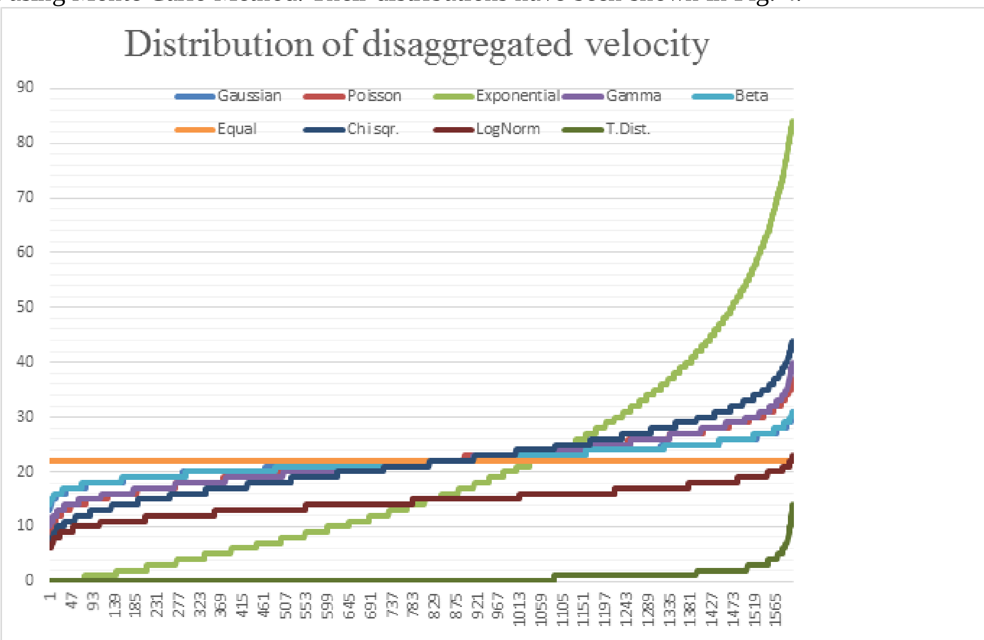


Fig. 4.
Nine Different Distribution of Disaggregated Velocity With Same Input Data

By taking all of these distributions into account in the mentioned interval (10 to 130 km/h), the samples would drastically decrease from 1600 vehicles to just 6 vehicles. Therefore, it was decided to get rid of T-distribution samples to cover more samples (about 1000 vehicles out of 1600 vehicles) as the inputs of emission models. Based on these speed distributions their related emission distributions were calculated. The results have been shown in Fig. 5.

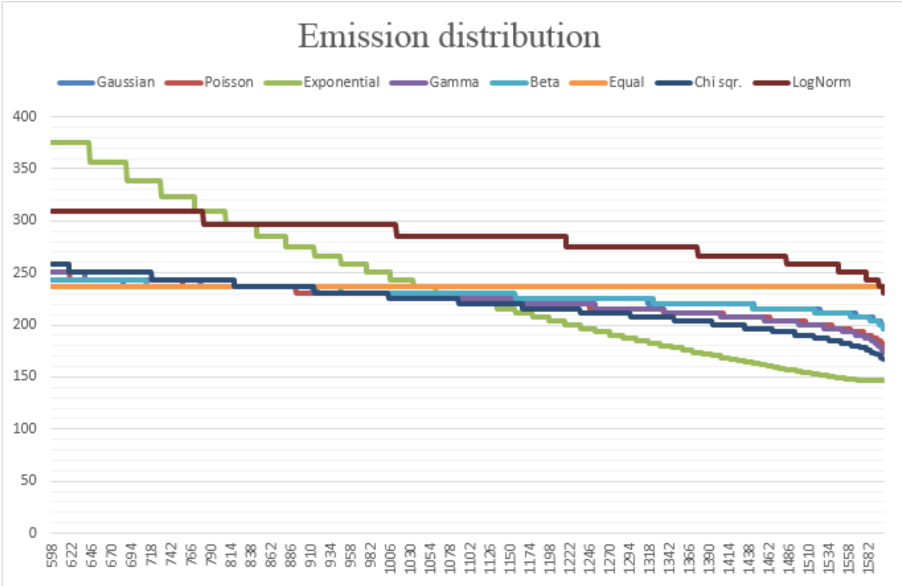


Fig. 5.
Eight Different Emission Distribution Based on Their Speed Distribution

4. Analysis and Discussion

The comparison of these emission distributions is shown in Fig. 6.

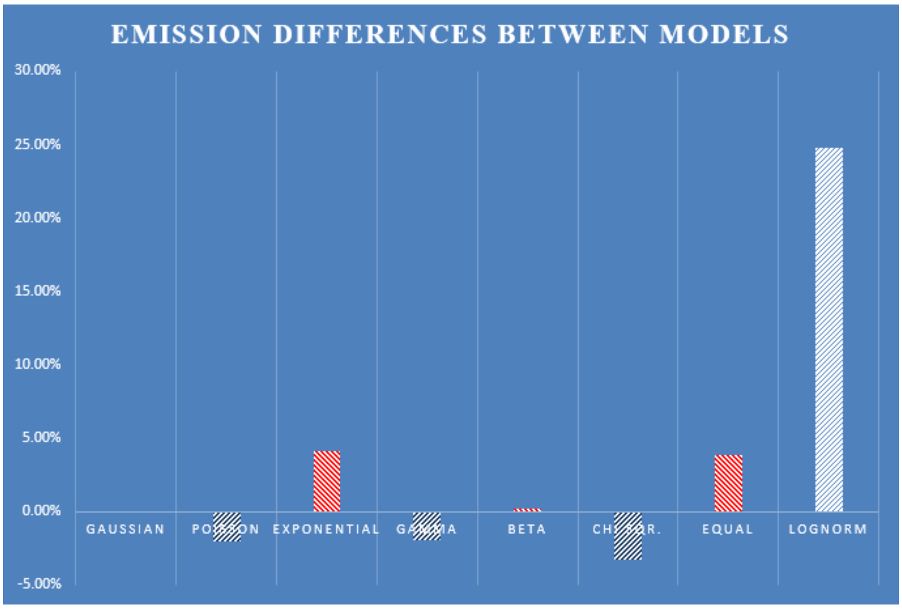


Fig. 6.
Comparing all emission models with Gaussian distribution

By taking a wide look at Fig. 6, it could be expected that the more precise distribution modelling would be useful and would cause significant differences in microsimulation and emission modelling.

5. Conclusion

In this paper, the authors introduced the speed distribution of the vehicular traffic flow in the evaluation of emission modelling. Any emission modelling made by unimodal traffic condition whereas the standard conditions are not negligible. By introducing the dependence of speed curve profiles, the authors developed a more realistic prediction tool, able to consider the intrinsic stochastic feature of traffic phenomenon. The study of the influence of different distributions on the resulting emission level has been performed. This result leads to the chance in revising the simulation software in further studies by extending these results in bimodal speed distributions and their related emission models. The considerable difference in the emission models related to Log-normal distribution as well as exponential, chi-square and equal distribution to normal Gaussian distribution implies that these different traffic conditions will have a considerable effect on emission even in the unimodal traffic conditions.

References

Ali A., Flannery A., and Venigalla M., 2007. Preciction Models for Free Flow Speed on Urban Streets, In *Proceedings of the 86th Annual Meeting of the Transportation Research Board*.

Batterman, S.; Zhang, K.; Kononowech, R. 2010. Prediction and analysis of near-road concentrations using a reduced-form emission/dispersion model. *Environmental Health*, 9(29): 1-18.

Donald S.B; Belmont, M.D. 1951. Distribution of Vehicle Speeds and Travel Times. In *Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability,* 589-602.

Aly, B.; Ramli, S.H.; Sumi, M.I.T. 2012. Driving Cycle of Passenger Cars on Heterogeneous Traffic Situations: Case Study on an Urban Road in Makassar, Indonesia. In *Proceedings of the of the 8th International Symposium on Lowland Technology*.

CARB 2002. EMFAC 2002, California Air Resources Board's Emission Inventory Series, September. Available from Internet: <http://www.arb.ca.gov//msei/on-road/latest_version.htm.>.

Castro M.; Sanchez J.A.; Vaquero C.M.; Iglesias L.; Rodriguez-Solano R. 2008. Automated GIS-based system for speed estimation and highway safety evaluation, *Journal of Computing in Civil Engineering*, 22(5): 325-331.

Satish, C.; Bharti, K.A. 2013. Speed Distribution Curves for Pedestrians During Walking and Crossing, *Procedia - Social and Behavioral Sciences*,104: 660-667.

Dey, P.P.; Chandra, S.; Gangopadhaya, S. 2006. Speed distribution curves under mixed traffic conditions, *Journal of transportation engineering*, 132(6): 475-481.

Dhamaniya, A.; Satish C. 2013. Speed Prediction Models for Urban Arterials Under Mixed Traffic Conditions, *Procedia - Social and Behavioral Sciences*, 104(12):342-351.

Dixon, K.K.; Wu, C.H.; Sarasua, W.; Daniel, J. 1999. Posted and Free-Flow Speeds for Rural Multilane Highways in Georgia, *Journal of Transportation Engineering*, 125(6):487-494.

DoTRS 2001. *Comparative Vehicle Emissions Study*, Commonwealth Department of Transport and Regional Services, Canberra, Australia.

EEA 2000. COPERT III Computer Programme to Calculate Emissions From Road Transport – Methodology and Emissions Factors (Version 2.1). In Ntziachristos, L.; Samaras, Z.; Eggleston, S.; Gorissen, N.; Hassel, D.; Hickman, A.-J.; Joumard, R.; Rijkeboer, R.; White, L.; Zierock, K.-H. (Eds.), November 2000, Technical Report No. 49. European Environment Agency, Copenhagen.

Fenger, J., 1999. Urban air quality. *Atmospheric Environment*, 33(29): 4877-4900.

Figueroa, A.; Tarko, A. 2004. *Reconciling Speed Limits with Design Speeds-HWA/IN/JTRP-2004/26,* Purdue Universit., West Lafayette, U.S.A.

Fitzpatrick, K.; Carlson, P.L.; Wooldridge, M.D.; Brewer, M.A. 2000. *Design factors that affect driver speed on suburban arterials, Report n. 1769-3*, Technical Report Documentation, Texas Transportation Institute, U.S.A.

Gao, S.,; Wang, Y.l Gao, Y.; Liu, Y. 2013. Understanding urban traffic-flow characteristics: a rethinking of betweenness centrality, *Environment and Planning B: Planning and Design*, 40(1): 135-153.

Gerlough, D.L.; Huber, M.J. 1975. *Traffic flow theory: a monograph-Special report 165*, Transportation Research Board, National Research Council, Washington, D.C., U.S.A.

Haight, F.A.; Mosher, W.W. 1962. *A practical method of improving the accuracy of vehicular speed distribution measurements, HRR 341*, Highway Research Board, Washington, D.C., U.S.A.

Harmonoise, 2004. Imagine project funded by EC under the sixth framework program. Available from Internet: <ttp://www.imagine-project.org>.

Himes, S.C., Donnel, E.T., 2010. Speed Prediction Models for Multi-Lane Highways: A Simultaneous Equations Approach, *Journal of Transportation Engineering*, 136(10): 855-862.

Hustim, M.; Fujimoto, K. 2012. Road Traffic Noise under Heterogeneous Traffic Condition in Makassar City, Indonesia, *Journal of Habitat Engineering and Design*, 4(1): 109-118.

Ramli, M.H. Isran, M. 2013. The Vehicle Speed Distribution on Heterogeneous Traffic: Space Mean Speed Analysis of Light Vehicles and Motorcycles in Makassar-Indonesia. In The Eastern Asia Society for Transportation Studies.

Yujie, H.; Wang, F. 2015. Decomposing Excess Commuting: A Monte Carlo Simulation Approach, *Journal of Transport Geography*, 44: 4352.

Iannone, G.; Guarnaccia, C.; Quartieri, J. 2013. Speed distribution influence in road traffic noise prediction, *Environmental Engineering And Management Journal*, 12(3): 493-501.

INFRAS 2007. Handbook Emission Factors for Road Transport – HBEFA. Available from Internet: <http://www. hbefa.net/.>.

Jun, J. 2010. Understanding the variability of speed distributions under mixed traffic conditions caused by holiday traffic, *Transportation Research Part C-Emerging Technologies*, 18(4): 599-610.

Katti, B.K., Shastri, A., Pathak, R.H. 1988. Free Constrained and bunching Vehicular Flow on Urban Arterials Under Mixed Traffic Conditions. In *Proceedings of the Indian Roads Congress,* 1-14.

Joonho, K.; Guensler, L.R. 2005. Characterization of Congestion Based on Speed Distribution: A Statistical Approach Using Gaussian Mixture Model. In *Proceedings of the Transportation Research Board Annual Meeting*.

Kroese, D.P.; Brereton, T.; Taimre, T.; Botev, Z.I. 2014. Why the Monte Carlo method is so important today, *WIREs Comput Stat*, 6(6): 386-392.

Leong, H.J.W. 1968. The distribution and trend of free speeds on two-lane two-way rural highways in New South

Wales. In *Proceedings of the 4th Australian road research board conference*, 14-16.
Lin, S,; He, M,; Tan, Y.; He, M. 2008. Comparison study on operating speeds of electric bicycles and bicycles: experience from field investigation in Kunming, China, *Transportation Research Record*, 2048: 52-59.
Loutzenheiser, D.W. Greenshields, B.D. 1940. Percentile Speeds on Existing Highway Tangents. In *Proceedings of the* Highway Research Board.
Maghrour, Z.M.; Torok, A.; Mandoki, P.; Toth, J. 2015. Maneuvers analysis of shared taxi and their effects on flow characteristics. In *Proceedings of the MT-ITS Conference*.
Maurya, A.K.; Das, S.; Dey, S. 2015. Speed and Time Headway Distribution under Mixed Traffic Condition. In *Proceedings of the 11th International Conference of Eastern Asia Society for Transportation Studies (EASTS 2015)*.
McFadden, J.; Yang, W.; Durrans, S. R. 2001. Application of Artificial Neural Networks to Predict Speeds on Two-Lane Rural Highways, *Transportation Research Record*, 1751: 9-17.
McLean J.R. 1978. Observed Speed Distributions and Rural Road Traffic Operations. In *Proceedings of the 9th Australian Road Research Board Conference*, 235-244.
Minh, C.C.; Sano, K.; Matsumoto, S. 2005. The speed, Flow and Headway Analyses of Motorcycle Traffic, *Journal of the Eastern Asia Society for Transportation Studies*, 6: 1496-1508.
Munawar, A. 2011. Speed and Capacity for Urban Roads, Indonesian Experience. In *Proceedings of the 6th International Symposium on Highway Capacity and Quality of Service*.
Namdeo, A.; Mitchell, G.; Dixon, R. 2002. TEMMS: an integrated package for modelling and mapping urban traffic emissions and air quality, Environmental Modelling & Software, 17(2): 179-190.
Ntziachristos, L.; Samaras, Z. 2012. *EMEP/EEA emission inventory guidebook 2009, updated May 2012*, European Environmental Agency, Copenhagen, Denmark.
Rao, A.M.; Rao K.R. 2015. Free Speed Modeling for Urban Arterials - A Case Study on Delhi, *Periodica Polytechnica Transportation Engineering*, 43(3): 111-118
Shankar, V.; Mannering, F., 1998. Modeling the Endogeneity of Lane-Mean Speeds and Lane-Speed Deviations: A Structural Equations Approach, *Transportation Research Part A*, 32(5):311-322.
Smit, R.; Brown, Al.; Chan, Y.C. 2008. Do air pollution emissions and fuel consumption models for roadways include the effects of congestion in the roadway traffic flow?, *Environmental Modelling and Software* 23(10-11): 1262-1270.
Tettamanti, T.; Milacski, Á.Z.; Lőrincz, A.; Varga, I. 2015. Iterative Calibration Method for Microscopic Road Traffic Simulators, Periodica Polytechnica Transportation Engineering, 43(2): 87-91.
TNO 2001. Emissions and Congestion – Estimation of Emissions on Road Sections and the Dutch Motorway Network. In: Gense, N.L.J., Wilmink, I.R., Van de Burgwal, H.C. (Eds.), Report No. 01.OR.VM.0441/NG. TNO Automotive, The Netherlands.
Torok, A. 2015. Monte-Carlo Simulation of Road Transport Emission, *International Journal for Traffic and Transport Engineering*, 5(3): 278-85.
Török, A.; Maghrour Z.M. 2016. Assessing the Need for Applying Multimodal Speed Distribution in Road Transport Macro Emission Estimation, *Acta Technica Jaurinensis*, 9(2): 118-127.
Trozzi, C.; Vaccaro, R.; Crocetti, S. 1996. Speed frequency distribution in air pollutants emissions estimate from road traffic, *Science of the Total Environment*, 189-l90: 181-185.
USEPA 2007. MOBILE 6 Vehicle Emission Modelling Software and Documentation. US Environmental Protection Agency, Washington, DC. Available from Internet: <http://www.epa.gov/ otaq/m6.htm.>.
Vadeby, A.; Forsman, A. 2014. Speed Distribution and Traffic Safety Measures. In *Proceedings of the Transport Research Arena (TRA) 5th Conference: Transport Solutions from Research to Deployment*.
Wang, D.; Zhou, D.; Jin, S.; Dongfang, M. 2015. Characteristics of mixed bicycle traffic flow on conventional bicycle path. In *Proceedings of the 94th annual meeting of the transportation research board*.
Wang, Y.; Dong, W.; Zhang, L.; Chin, D., Papageorgiou, M.; Rose, G.; Young, W. 2012. Speed modeling and travel time estimation based on truncated normal and lognormal distributions, *Journal of the Transportation Research Board*, 2315: 66-72.
Watanatada, T.; Ben-Akiva, M. 1979. Forecasting urban travel demand for quick policy analysis with disaggregate choice models: a Monte Carlo simulation approach, *Transportation Research Part A: General*, 13(4): 241-248.
Wegener, M. 1985. The Dortmund housing market model: a Monte Carlo simulation of a regional housing market. *Lecture Notes in Economics and Mathematical Systems*, 239: 144-191.
Zou, Y. 2013. *A Multivariate Analysis of Freeway Speed and Headway Data*, A&M Transportation Institute, Texas, U.S.A.
Zou, Y.; Zhang, Y. 2011. Use of Skew-Normal and Skew-t Distributions for Mixture Modeling of Freeway Speed Data, *Journal of the Transportation Research Board*, 2260: 67-75.

POTENTIAL OF TROPOSPHERIC OZONE FORMATION FROM SOLVENTBORNE ROAD MARKING PAINTS IN ADRIATIC SEA BASIN

Tomasz E. Burghardt[1], Anton Pashkevich[2], Lidia Żakowska[3]
[1] *M. Swarovski GmbH; Industriestrasse 10, 3300 Amstetten, Austria*
[2,3] *Kraków University of Technology, Civil Engineering Department, Transport Section; ul. Warszawska 24, 31-155 Kraków, Poland*

Abstract: Ground-level ozone is a significant pulmonary irritant, responsible for numerous of premature deaths worldwide. Ozone forms during solar irradiation-mediated decomposition of nitrogen dioxide to nitrogen oxide, which leads to its high levels in areas of high insolation. Volatile Organic Compounds (VOC) undergo decomposition *via* photolysis and interact with nitrogen oxide, pushing the reaction equilibrium to increased ozone formation. Different solvents decompose in the atmosphere by different chemical pathways and thus have dissimilar effect on the ozone formation; the effects were quantified in their Maximum Incremental Reactivities (MIR). Solventborne road marking paints contain about 24% of VOCs, which affect ozone formation; therefore, it is critical that the solvents are selected to minimise the negative effects. In this contribution, MIR were used to calculate tropospheric ozone formation potential from several road marking paints used in Adriatic Sea basin, where there are specific issues associated with very high insolation and where weather conditions favour high ozone concentration episodes. It was calculated that well-designed waterborne road marking paints can have 27-fold lower ozone formation potential than toluene-based paints, in addition to furnishing 85% lesser VOC emissions.

Keywords: tropospheric ozone, maximum incremental reactivity, volatile organic compounds, waterborne road marking, solventborne paints, horizontal road markings, glass beads.

1. Background

Tropospheric ozone is formed from nitrogen dioxide, which under photolytic conditions is decomposing to nitrogen oxide and oxygen radical, per mechanism proposed by Chameides and Walker (1973). The levels of nitrogen oxide, nitrogen dioxide, and ozone form equilibrium. VOCs, which decompose *via* hydroxy radicals, affect the equilibrium by reacting with nitrogen oxide, which was first observed by Leighton (1961) and elucidated by Crutzen (1974). Generally, the decomposition products of VOCs increase formation of ozone. Carter (1994) has quantified the effect of particular VOCs on ozone formation and developed MIR.

Horizontal road markings are amongst the most commonly used and most effective safety features on all of the modern roads. Current technologies do not permit for their replacement with any other means. The markings are systems consisting of pigmented layer and reflective elements. Various types of road markings were recently reviewed by Babić and colleagues (2015).

Emissions of solvents from solventborne road marking paints affect formation of ground-level ozone, as we have reported in two preceding papers concentrating on emissions in Poland (Burghardt et al., 2016, 2016a). Herein, we discuss several specific issues associated with high-insolation areas and regions prone to high ozone concentrations and analyse several road marking paints used in this region in terms of their potential of ground-level ozone formation.

1.1. Tropospheric ozone

Ozone, a tri-molecular allotrope of oxygen, forms in the atmosphere during lightning and is present mostly in the stratosphere, where it is required as a scavenger of ultraviolet radiation. In troposphere, ozone is rather undesired, because it is a reactive species that causes irritation to respiratory system, it is a significant component of summertime non-particulate smog. Simultaneously, one must remember that it is a critical part of troposphere's self-cleaning processes. A plethora of reports link increased ground-level ozone concentration with increased mortality and morbidity: Amman (2009) estimated that loss of 22 thousand of lives in 25 countries subjected to the evaluation in 2008 could be linked to tropospheric ozone. An OECD report (2012) indicated annual worldwide premature deaths caused by ground-level ozone pollution, after statistical separation from the effects of other air contaminants, to be between 50 000 and 350 000.

In addition to being harmful to humans, tropospheric ozone causes damage to plants, in some cases quite severe (Fumagalli et al., 2001).

Annually-averaged background ozone concentration in areas devoid of industrial or man-made sources was reported by Vingarzan (2004) to have risen by up to 50% over the past 100 years in for mid-latitudes of Northern Hemisphere regions.

1.2. Tropospheric ozone in Mediterranean basin

Mediterranean basin is quite a specific area due to high insolation, high emissions of ozone precursors, and weather conditions. During summer, stable high air pressure and anti-cyclonic air circulation favour ozone formation and

[3] Corresponding author: lzakowsk@pk.edu.pl

disfavour its natural titration by nitrogen oxide. Ozone reservoirs are formed off-shore because at night the land breezes move the ozone-polluted air to stay above the sea; the air masses then return to the shore during daytime to add to ozone pollution. The prevailing calm winds do not afford sufficient dispersion of the pollutants. Such air masses movements were reported by Prtenjak et al. (2013) as responsible for a high-ozone episode that occurred in Rijeka, Croatia in 2000 when night-time ozone level was exceeding 100 μg/m³ and during the day was around 180 μg/m³. Due to the same transport mechanism, high ozone concentrations can also occur at remote sites (Monteiro et al., 2012).
Quite interestingly, analysis of ozone concentration levels from 214 measuring stations in Mediterranean region over the first decade of 21st century demonstrated that at rural stations ozone concentrations were decreasing by an average of 0.43% annually. Simultaneously, at suburban and urban stations the average levels were increasing respectively by 0.46% and 0.64% per year. The increases in urban area were attributed, paradoxically, to stricter vehicular emissions controls that lowered the availability of nitrogen oxides (Sicard et al., 2014).

1.3. Horizontal road markings systems

Horizontal road markings are ubiquitous road safety feature. Their influence on environment can be profound and numerous legislations throughout the world have been imposed to limit the use of various substances that may be harmful to human health or safety and the environment. Modern road marking materials are devoid of heavy metals and chlorinated solvents. In some countries, also aromatic solvents are prohibited or limited and restrictions on VOC emissions are imposed. Solvent- or water-borne paints, coldplastic, and thermoplastic masses are the most commonly used pigmented layers.
The best analysis to seek minimum environmental impact appears be the use of cradle-to-grave Life Cycle Assessment (LCA). Such analysis recently performed on water- and solvent-borne road marking paints demonstrated that the key parameter was **system durability**. However, even though the LCA included the environmental impact of the emitted VOCs, we have questioned whether the location of emissions and ozone formation potential should not be considered as an important additional factor in the light of the impact of tropospheric ozone and other pollutants on human health (Burghardt et al., 2016a).
The influence of horizontal road marking paints on VOC emissions has been recognised by various environmental authorities and norms were established. However, it only seems reasonable to assume that improvement in air quality in areas of high ozone concentrations can be accomplished by minimising the emissions of VOCs that have highest MIR. A recent analysis from South California Air Quality Management District (SCAQMD), for which the MIR scales were developed, has shown that traffic paints along with related coatings contributed 1.1 tonnes of VOCs per day in the SCAQMD area comprising 27 850 km² and inhabited by almost 18 million people. Reactivity-weighted emissions, based on MIR analyses, were calculated to be similar (Chen and Luo, 2012).
A key component in road marking systems are drop-on glass beads that provide retroreflectivity at night and simultaneously protect the pigmented layer. The selection and quality of glass beads is one of the critical parameters, possibly the most important, for systems durability. At this Conference and at European Road Infrastructure Congress is being demonstrated that the use of highest quality glass beads leads not only to exquisite retroreflectivity, but also to exceptional systems durability (Mosböck and Burghardt, 2016; Burghardt, Babić, and Babić, 2016). Thus, glass beads for road marking may indirectly also affect the amounts of emissions of solvents and potential of ground-level ozone formation.

2. Methodology

In our analysis, we are utilising MIR rather than VOC emissions to assess the effects of solvents from road marking paints on environment. The use of MIRs, which are expressed in the unit of grams of potentially formed ozone per gram of VOC, makes calculations very simple and straightforward. From chemistry point of view, the unit is quite strange, because all chemical reactions are taking place on molar basis, but the scales were developed for SCAQMD, which deals with tonnes of emissions. MIR values published in California Code of Regulations, Title 17, Chapter 8, §94700 are used.
Similarly to our (2016) analysis done on road marking paints in Poland, we have used freely available Safety Data Sheets (SDS) of a few solventborne road marking paints as the source of solvent composition. For simplicity, in all of the cases we have assumed the volatile materials content at 24%; where concentrations ranges were given, we have taken the proportional amounts to obtain 24% of volatiles. We were not able to obtain the amounts of actually utilised solventborne paints, because such information is proprietary to the road marking companies. It is due to the existence of full maintenance contracts (including, in addition to maintaining the horizontal markings, also work needed for vertical markings, cleaning, mowing grass, snow removal, etc.).
It has to be noted that MIR assume a worst-case scenario, where there is high insolation, corresponding to measured at 35° latitude, and unlimited supply of nitrogen dioxide (Carter, 1994). Such conditions are present in the Mediterranean basin even if majority of the affected area is not located as far south as was used for MIR conditions.
During the episodes of high ozone or when weather conditions favour formation of tropospheric ozone and its retention off-shore and return to the land, the removal of tropospheric ozone precursors like those present in solventborne road marking paints appears critical.

3. Results and discussion

3.1. Influence of solvent choice on ozone formation potential

Firstly, the profound influence of solvent choice on ozone formation potential has to be illustrated. One can take the strictest VOC emission rules for road marking paints in Europe: In Scandinavia, maximum VOC emissions cannot exceed 2%, which effectively eliminated solventborne road marking from that region. However, the 2% emissions do not specify what solvent can be used. Assuming the same VOC limit of 2%, from 1 kg of applied road marking paint can be potentially produced between 7.2 g and 77.6 g of ozone, a tenfold difference, as shown in Table 1. Ethanol, which is almost always added to waterborne road marking paints, does have a noticeable tropospheric ozone formation potential despite its relatively low toxicity. Furthermore, one has to remember that the coalescent (Texanol®) is not a VOC according to European regulations (it is a VOC according to the North American regulations) but it does evaporate, albeit extremely slow, and has an ozone-formation potential. A question arises how such a chemical should be treated.

Table 1

Solvents and possible different tropospheric ozone formation (assuming 2.0% VOC)

Solvent	MIR	Ozone formation potential [g O_3/kg paint]
Methyl isobutyl ketone	3.88	77.6
1-methoxypropan-2-yl acetate	1.70	34.0
Ethanol	1.53	30.6
Methyl ethyl ketone	1.48	29.6
Butyl acetate	0.83	16.6
Texanol®[(a)]	0.81	16.2
Acetone	0.79	7.2
(a) Coalescent, which is not a VOC according to the regulations; added typically at 1.5-3.5%, depending on the binder type and content. Here, it is assumed to be at 2.0%.		

3.2. Solventborne road marking paints and potential of ozone formation

Solventborne road marking paints are being commonly used, because of their availability, low price, and ease of applications, even if their durability is not the highest. In areas where the use of toluene, an aromatic solvent, is not specifically banned or restricted by law, it is being used. Some of the advantages of using toluene as a solvent for road marking paints were recently discussed by us (2016).

We have done our analysis on four solventborne paints that are used in the Adriatic sea basin and included a typical waterborne paint for comparison. The compositions of volatiles disclosed in the SDS and the potentially formed ozone are listed in Table 2.

Solventborne paints used in the western Balkans (paints 1 and 2) contain toluene as an exclusive solvent. Therefore, potential of ozone formation is very high, reaching even 958 g per kg of applied paint. With typical spreading rate of 600 g/m² and line width of 15 cm, there is a possibility of formation of up to 86 g of ozone per linear metre of applied marking! A report (Tebert, 2011) estimated the usage of solventborne paints usage in Croatia in 2006 at 1069 tonnes. VOC emissions from such quantity of paint would be 257 tonnes and the emitted VOC could lead to formation of over 1000 tonnes of ozone with paints 1 or 2! This calculation only demonstrates the enormous quantities of emissions and potential of ozone formation in the worst case scenario and it ought to be understood that weather conditions profoundly influence the actual formed tropospheric ozone. In case of paint 3, addition of acetone as co-solvent leads to meaningful lowering of ozone potential formation

Solventborne paint produced in Italy are toluene-containing (paint 4) or aromatic-free (paint 5) systems. VOC emissions from such paints are equally large, but the amount of potentially formed ozone of aromatic-free paint 5 is significantly lesser. Hence, the estimated 5691 tonnes of solventborne paints annually used in Italy (Tebert, 2011) translates to emissions of 1366 tonnes of VOCs, which could lead to production of ozone between 1414 (paint 5) and 2745 tonnes (paint 4). One must note here that essentially all of Italy is a non-attainment area in terms of ozone pollution.

Waterborne road marking paint (paint 6) has VOC emissions of only 1.5% (according to the European regulations) and those VOCs can lead to formation of only 36 g of ozone per kilogram of paint. If all paints in Italy were switched to waterborne, emissions would be lowered to only 85 t of VOCs (94% reduction) that could yield up to 205 t of tropospheric ozone (83% reduction).

Table 2
Maximum tropospheric ozone formation from various paints (assuming 24% solvents)

		Paint system					
Solvent	**MIR**	**1**	**2**	**3**	**4**	**5**	**6**
Toluene	4.00	23.6%	23.9%	17.5%	11.0%		
Methyl ethyl ketoxime	1.58		0.1%	0.2%			
Butyl acetate	0.83	0.4%			2.0%	18.0%	
Ethyl acetate	0.63					1.5%	
Methyl acetate	0.07				4.5%		
2-butoxyethyl acetate	1.62					1.5%	
Methyl ethyl ketone	1.48					7.5%	
Acetone	0.79			6.3%	3.5%		
Methanol	0.67				1.5%		
Ethanol	1.53						1.0%
Butanol	1.88					1.5%	
Texanol®	0.81						3.5%
C14-C17 chlorinated paraffin	0.00				1.5%		
Ammonium hydroxide	0.00						0.5%
Water	0.00						19.0%
Maximum ozone formation [g O_3/kg paint]		**944**	**958**	**726**	**482**	**249**	**36**

It is extremely difficult – if at all possible – to measure what percentage of VOCs are converted to tropospheric ozone, because marking is frequently done after sundown and when ambient temperatures are not extremely high. However, in such cases, the solvents are migrating to the stratosphere, where they undergo decomposition — and often create even more harm to the global environment.

3.3. Viable solution

The use of waterborne road marking systems, particularly with glass beads furnishing extended durability, could lead to very significant decrease of VOC emissions and the levels of ground-level ozone. The decreases could be 27-fold when one compares the reduction in potentially formed ozone from toluene-based and waterborne road marking paints. Such reduction would translate to improved health of the application crews, the citizens, and our planet. Alternatively, one could use solvent-less systems; however, such systems are more expensive to purchase and apply and they may be an over-engineered solution for a plethora of roads. Road authorities and the applicators ought to consider the utilisation of readily available solutions that are less harmful for the environment.
It is obvious that the emissions from sources other than road marking materials are significantly higher. However, the contribution of road marking paints to the VOC emissions and their ozone formation potential can be easily lowered, which is particularly important in area prone to high ozone episodes and where the weather conditions generally favour the use of waterborne materials, notwithstanding their higher durability.

4. Conclusions

Solvents from road marking paints are VOCs and thus affect the formation of tropospheric ozone. Their influence varies depending on their decomposition pathways, climatic conditions, and the presence of other pollutants. Adriatic Sea basin, where summertime insolation and temperature are very high, is supporting formation of tropospheric ozone and indeed there are quite frequent episodes where the norms are exceeded significantly.
The use of waterborne road marking paints is a viable environmentally-friendly alternative to the currently used solventborne materials. Waterborne road marking systems are not only easy to apply and durable, but also have lower negative effect on our and our planet's health. Reduction of the possibility of tropospheric ozone formation may be

enormous: Whereas a toluene-based solventborne road marking paint can produce up to 958 g of ozone per kilogram of applied paint, waterborne road marking paint of better durability has the potential reduced 27-fold, to only 36 g O_3/kg.

Note

All of the Tables reported herein are provided by the Authors.

References

Amman, M. 2009. *Health risks of ozone from long-range transboundary air pollution*, World Health Organisation, ISBN: 978-92-890-4289-5.

Babić, D.; Burghardt, T.E.; Babić, D. 2015. Application and Characteristics of Waterborne Road Markings Paint, *International Journal for Traffic and Transport Engineering*, 52: 150-169.

Burghardt, T.E.; Babić, D.; Babić, D. 2016. Application of Waterborne Road Marking Paint in Croatia: Two Years of Road Exposure, *International Conference of Transport and Traffic Engineering; Belgrade, Serbia, 24-25 November 2016* (in press).

Burghardt, T.E.; Pashkevich, A.; Żakowska, L. 2016. Contribution of solvents from road marking paints to tropospheric ozone formation, *Budownictwo i Architektura*, 15: 7-18.

Burghardt, T.E.; Pashkevich, A.; Żakowska, L. 2016a. Influence of Volatile Organic Compounds Emissions from Road Marking Paints on Ground-level Ozone Formation: Case Study of Kraków, Poland, *Transportation Research Procedia*, 14: 714-723.

Carter, W.P.L. 1994. Development of Ozone Reactivity Scales for Volatile Organic Compounds, *Journal of Air and Waste Management Association*, 44: 881-899.

Chameides, W.; Walker, J.C. 1973. A photochemical theory of tropospheric ozone, *Journal of Geophysical Research*, 78: 8751-8760.

Chen, J.; Luo, D. 2012. Ozone formation potentials of organic compounds from different emission sources in the South Coast Air Basin of California, *Atmospheric Environment*, 55: 448-455.

Crutzen, P.J. 1974. Photochemical reactions initiated by and influencing ozone in unpolluted tropospheric air, *Tellus*, 26: 47-57.

Fumagalli, I.; Gimeno, B.S.; Velissariou, D.; De Temmerman, L.; Mills, G. 2001. Evidence of ozone-induced adverse effects on crops in the Mediterranean region, *Atmospheric Environment*, 3514: 2583-2587.

Leighton, P. 1961. *Photochemistry of air pollution*, Academic Press, ISBN: 978-0124422506.

Monteiro, A.; Strunk, A.; Carvalho, A.; Tchepel, O.; Miranda, A.I.; Borrego, C.; Saavedra, S.; Rodríguez, A.; Souto, J.; Casares, J.; Friese, E.; Elbern, H. 2012. Investigating a high ozone episode in a rural mountain site, *Environmental Pollution*, 162: 176-189.

Mosböck, H.; Burghardt, T.E. 2016. The Importance of Road Markings for Road Safety and Modern Traffic Management, *European Road Infrastructure Congress; Leeds, the United Kingdom, 18-20 October 2016* (in press).

OECD Organisation for Economic Cooperation and Development 2012. OECD Environmental Outlook to 2050: The Consequences of Inaction: The Key Findings on Health and Environment, http://www.oecd.org/environment/outlookto2050. Accessed 22.09.2015.

Prtenjak, M.T.; Jeričević, A.; Klaić, Z.B.; Alebić-Juretić, A.; Bulić, I.H. 2013. Atmospheric dynamics and elevated ozone concentrations in the northern Adriatic, *Meteorological Applications*, 204: 482-496.

Sicard, P.; De Marco, A.; Troussier, F.; Renou, C.; Vas, N.; Paoletti, E. 2013. Decrease in surface ozone concentrations at Mediterranean remote sites and increase in the cities, *Atmospheric Environment*, 79: 705-715.

Tebert, C.; Volz, S.; Müller, W.; Theloke, J. 2011. Review of directive 2004/42/EC, Ökopol GmbH, Institute for Environmental Strategies, Hamburg.

Vingarzan, R.; 2004. A review of surface ozone background levels and trends, *Atmospheric Environment*, 38: 3431-3442.

EFFECTIVE FLEET MAINTENANCE PLANNING WITH THE AIM OF ACHIEVING ENERGY-EFFICIENT AND RATIONAL REALIZATION OF TRANSPORTATION PROCESS

Davor Vujanović[1]
[1] *University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, Belgrade, Serbia*

Abstract: The companies which own vehicle fleet for carriage of goods are considered in this paper. The main objective of considered companies is to accomplish all the planned transportation tasks while minimising transportation and maintenance costs in the opserved period, which leads to higher profit. In this sense, the influence of effective maintenance planning on the achievement of defined objective of observed companies is researched in this paper. For this purpose, a study was conducted in several observed companies in Serbia, in terms of existing maintenance planning. The conducted study shows which part of maintenance work is realized in own maintenance facilities of the companies, and which part in the external specialized vehicle service center (SVSC) in the region. In order to make a decision in choosing a SVSC, managers take in consideration the several different factors (criteria). Based on conducted survey, the paper defines the relevant factors that affect the mentioned decision when planning maintenance work. It has been found on which factors managers should pay more attention when making considered decision in order to become effective maintenance planning and to realise the given transport volume in an energy-efficient and rational way.

Keywords: maintenance planning, specialized vehicle service center, vehicle fleet, energy efficiency.

1. Introduction

The research presented in this paper deals with companies owning light commercial or heavy goods vehicle fleets. The transportation services bring profit to the observed companies. In order to maximize their profit, companies are dedicated to accomplish all planned transportation tasks in certain period, with minimizing transportation and maintenance costs.

One way to achieve defined company objective is achievement of an effective fleet maintenance management. Since vehicles represent mobile assets permanently in contact with environment, the external environment factors have influence on vehicle maintenance process and transportation process. In this sense, to achieve an effective fleet maintenance management it is necessary to simultaneously and jointly observe: the transportation process, the vehicle maintenance process and the environment (Vujanovic et al., 2012).

According to statement of many authors (Ashayeri et al., 1996), (Brandolese et al., 1996), (Dhillon, 2002), (Johnson, 2002), (Mobley et al., 2008), one of the most important activities within maintenance management is maintenance planning. In that manner, this paper tries to indicate an importance of fleet maintenance planning on energy-efficient and rational realization of transport process and thus on achieving defined objective of observed companies.

The maintenance planning activity involves planning of timeframes in which preventive and other planned maintenance interventions should be realized, planning of dedicated maintenance manpower needs as well as necessary spare parts and materials, along with the timing of their procurement (Ashayeri et al., 1996). Within fleet maintenance planning, managers make also a decision where to perform the required maintenance work, for each vehicle request. In this respect, managers can make a decision to perform the maintenance work in company's own maintenance facilities or externally in specialized vehicle service centers in the region. Managers make a decision to perform maintenance work in a specialized vehicle service center (SVSC) in the region in a case when companies do not own adequate maintenance facilities or when in required timeframe their maintenance facilities are unavailable.

Selection of a SVSC in the region where will be executed the planned maintenance work is a managers decision which is affected by many different factors (criteria). In order to make the right decision in choosing a SVSC in the environment by managers and thus to make fleet maintenance planning more effective, it is important to define relevant factors that play significant role in this decision. In this sense, this paper represents a conducted research with the aim of defining relevant factors that affect a decision of selection the SVSC in the region where planned maintenance work will be executed.

For this purpose, the paper is structured as follows. The chapter 2 describes the activity of fleet maintenance planning. Based on the conducted study in some companies in the Republic of Serbia, the existing fleet maintenance planning activity is presented in chapter 3. In chapter 4 a survey on defining the relevant factors influencing the selection of a suitable SVSC in the region is presented. Conclusions are given in chapter 5.

2. Activity of fleet maintenance planning

The maintenance planning is an activity that predetermines operations, methods, materials, tools, equipment, labor, required time and deadlines for performing maintenance procedures (BS3811, 1984). According to paper (Gits, 1994), the importance of properly maintenance planning is reflected in following: contributes to reduce the number of

[1] Corresponding author: d.vujanovic@sf.bg.ac.rs

unexpected breakdowns; contributes to reduce the number of disturbance in maintenance process; as result of delivering product on time, affects the reduction of lost customers number; through the adequately perform of preventive interventions, affects the reduction of repairs cost and retains the performance of technical system within projected values; through the use of Maintenance Plan contributes to reduction the costs of electricity, gas and water in the maintenance facilities; ensures the existence of adequately spare parts in the required timeframe. According to authors (Mobley et al., 2008), maintenance planning activity relates to the preparation of work that should be performed in the future.

The fleet maintenance planning is an activity that is carried out at the operational level of maintenance management. This activity is conducted the most commonly by maintenance managers or fleet managers. As shown in Figure 1, through the conducting of maintenance planning activity, it is necessary that managers take into jointly considerations: informations of own vehicles; informations of fleet operations (*Operational Plan-OP*); informations of own maintenance workers, equipments and capacities; legislation that affects safe road traffic, and environmental protection; vehicle dealers' conditions regarding the warranty period; recommendations of vehicle manufacturers in terms of preventive maintenance; locations and quality-of-service of SVSC in the region, quality-of-service of spare parts' and materials' suppliers; informations based on conducted analysis of fleet maintenance job.

In this respect, managers have to ensure and prepare all the conditions in form that planned maintenance work is carried out without disturbances and in aim with defined company objective. For each registered vehicle maintenance request, they make decisions about the following issues:

1) location of maintenance work realization (in the company's own facilities, or in a specialized vehicle service center in the region);
2) timeframe of maintenance work realization;
3) required workforce of particular professions and the quantity of certain spare parts and materials (if maintenance work will be performed in company's own facilities);
4) Measures that have to be implemented to avoid or decrease disturbances during the maintenance work realization.

In cases when companies don't have their own maintenance objects or when a suitable equipment or workspace in the existing maintenance object is missing, managers have to make a decision on appropriate SVSC in the region where to carry out planned maintenance interventions on specific vehicle. Moreover, managers make this decision in the cases when workers of required professions are unavailable, when adequate vehicle workspaces are unreachable, when existing equipment is defective, etc.

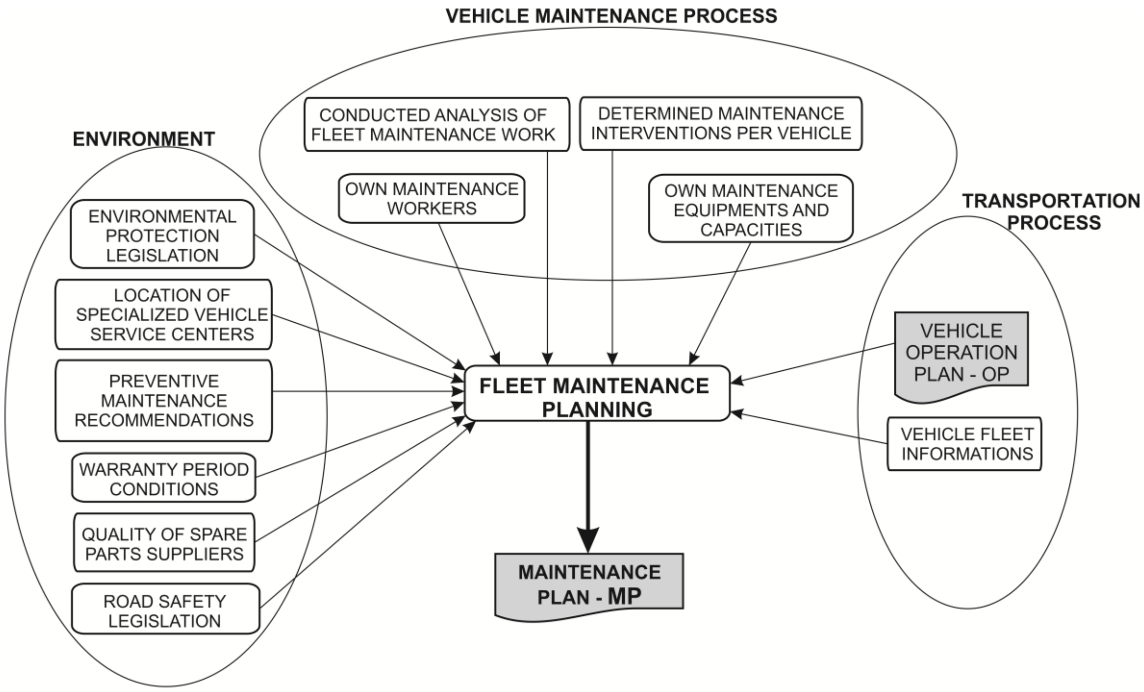


Fig. 1.
Position of fleet maintenance planning

Formalized form that describes the process of conducting of maintenance planning activity is represented by the document called *Maintenance Pla*n (MP). This document (Figure 2) represents a basic tool in the fleet maintenance management and the managers are in charge of filling this document adequately, while making the decisions on place and time of realization of specific vehicle maintenance interventions (Momčilović et al., 2007). The indicator *Maintenance Plan Realization* is the most important indicator of effective fleet maintenance management (Vujanović et al., 2012).

MAINTENANCE PLAN														
Vehicle ID	Maintenance location	Planned / realized exclusion from exploitation		Odometer state (in *km*)	Planned / realized start of maintenance interventions		Name of maintenance intervention	Numb. of workers	Quantity of spare parts	Planned / realized completion of maintenance interventions		Planned / realized inclusion in exploitation	
		Date	Time		Date	Time				Date	Time	Date	Time
...	...	...	...	...	...	...	...	...	...	...	...	...	...
		...	...		...	...				...	...	...	...

Fig. 2.
Preview of document Maintenance Plan (MP)
Source: (Vujanovic, 2013)

Effective maintenance planning allows managers to have an available vehicle from the most suitable *Construction-Operation* (CO) group for the implementation of transportation tasks in the required time. It has an influence on better cargo capacity usage per realized transportation volume which leads to an increase of fleet energy efficiency and decrease transportation costs (Kamakat and Schipper, 2005), (Ruzzenenti and Basosi, 2009), (Vujanović et al., 2010). Moreover, the effective maintenance planning affects the reduction of number of backup vehicles, for the actual transportation process. It decreases the total fleet size and makes the fleet more rational, which has an influence on decreasing the transportation and maintenance costs (Vujanović et al., 2013).

3. Fleet maintenance in some companies in Serbia

In order to analyze the current situation in some companies in Serbia regarding the fleet maintenance, a study in the period of the end 2015 to the first quarter of 2016 was conducted. Only the companies with own fleets dealing with freight transportation in Serbia were analyzed in the study.
The aim of study was to examine which part of maintenance work (in percent) is executed in own maintenance facilities of the companies, and which part in the external SVSCs in the region.
In Table 1 the analyzed companies in conducted study are presented. As shown in Table 1, the average fleet size of observed companies is 125 vehicles, and their average age is about 5.8 years. In average 82% of total vehicle number in the companies are out of manufacturer warranty period.

Table 1
An overview of analyzed companies with fleet data

Company name	Vehicle fleet size	Average vehicle age (in years)	Number of vehicles out of manufacturer's warranty
AKS Express Kurir, Ltd.	456	3.5	338
Banini, Inc.	4	10	4
BEX Express, Ltd.	292	10	292
Centrosinergija, Ltd.	104	1	10
City Express, Ltd.	218	6	196
Delmax, Ltd.	33	5	28
G4S Secure Solutions, Ltd.	106	8	106
Mercator-S, Ltd.	141	3.5	95
Milšped, Ltd.	51	7	51
Nelt Co, Ltd.	203	4.2	196
Nestle Adriatic S, Ltd.	2	5	2
Nordex, Ltd.	5	7	5
Pelexino, Ltd.	22	7	22
Veletabak, Ltd.	116	4	98

The most of the analyzed companies own a fleet up to 50 vehicles (Figure 3). More than 200 vehicles have 4 of the analyzed companies. As shown in Figure 4, the most common type of vehicle in the analyzed companies are vans of total permissible weight up to 3.5 tons, which makes 69% of the total number of vehicles.

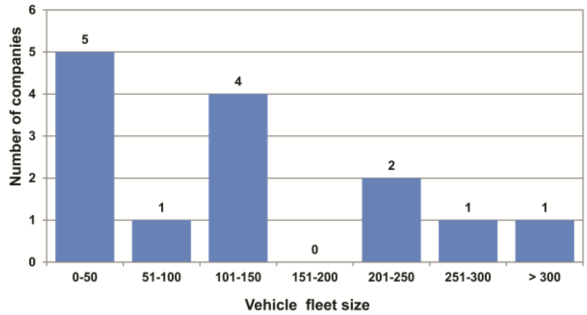


Fig. 3.
Vehicle fleet size in the analyzed companies

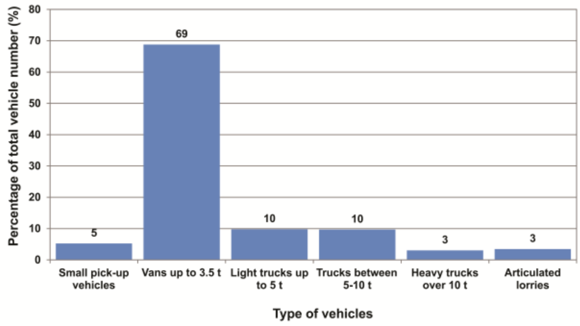


Fig. 4.
Share of vehicle type in the analyzed companies

According to conducted study, 8 analyzed companies don't have their own maintenance facilities, i.e. don't have their own workplaces for performing the maintenance interventions on vehicles (Figure 5). Only one company has more than 2 maintenance workplaces. This fact shows that managers in many of analyzed companies largely plan to accomplish the maintenance work in specialized vehicle service centers (SVSCs) in the region. In Figure 6, a relationship of maintenance work performed in SVSCs and maintenance work performed in companies' own facilities is shown. As shown in Figure 6, a significantly higher share of maintenance work performed in SVSCs have 11 companies. Only 2 of analyzed companies have a higher share of maintenance work performed in their own facilities during the observation period.

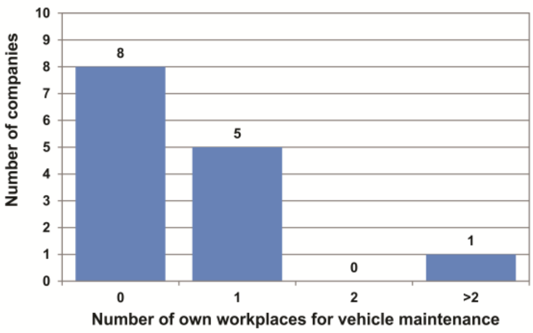


Fig. 5.
Number of maintenance workplaces in the analyzed companies

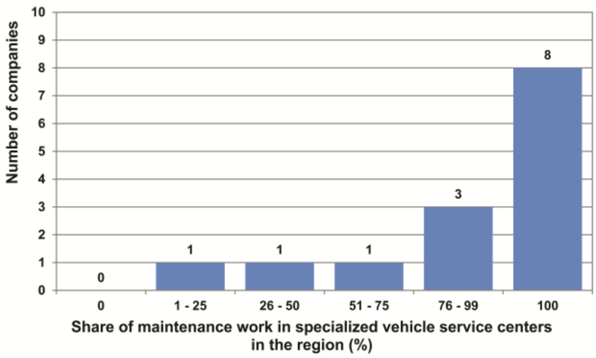


Fig. 6.
Share of performed maintenance work in SVSCs in the region vs. performed maintenance work in companies' own maintenance facilities

According to facts in conducted study, it can be concluded that managers of the considered companies very often make decisions on performing the planned maintenance work in SVSCs in the region. In order to effectively plan the fleet maintenance, among other things, managers have to make the right decisions about the selection of a suitable SVSC in the region where to carry out planned maintenance interventions on vehicle. The observed decision affects the energy efficiency and has an influence on rational realization of the given transportation process. In this respect, the right decisions about the selection of a suitable SVSC in the region contribute significantly to achieving of defined companies' objective.

However, managers take into consideration several different factors (criteria) while making mentioned decision. In this sense, it is necessary to define the relevant factors influencing the mentioned decision. In the next section of this paper is presented a conducted research on defining the relevant factors influencing the selection of a suitable SVSC in the region.

4. Research on defining the relevant factors

With the aim to finding the relevant factors that play an important role on managers' decision making in the selection of a suitable SVSC in the region, a research was carried out. For this purpose, an expert opinion survey was implemented. A survey involved 38 experts, of which 6 professors from the Faculty of Transportation and Traffic Engineering, University of Belgrade. The remaining 32 experts are transportation professionals with Master or Bachelor degrees in transportation engineering. All the experts involved in the survey are experienced in the area of vehicle fleet operation and maintenance. The survey was executed at the beginning of 2016.

During the survey, the experts were answered which factors in their opinion have a significant impact in the selection of SVSC in the region. On the basis of experts' responses in the survey and according to author personal experience in the observed field, in Table 2 the relevant factors were presented. As shown in Table 2, there are 11 factors that influencing significantly the decision making in the selection of suitable SVSC in the region where the planned maintenance work will be realized.

Table 2
Review of relevant factors influencing the decision making in the selection of suitable SVSC in the region where the planned maintenance work will be realized

Number	Relevant factors
1.	Maintenance Service Realization Costs in the SVSC
2.	Vehicle Travel Costs to the SVSC
3.	Payment Amenities for Maintenance Service granted by the SVSC
4.	Performed Maintenance Interventions' Quality by the SVSC (company’s experience)
5.	Respecting Agreed Timeframe by the SVSC (company’s experience)
6.	Performed Maintenance Interventions’ Speed by the SVSC (company’s experience)
7.	Location (Distance) of the SVSC
8.	Accessibility of the SVSC
9.	Service Network Development Level of the SVSC
10.	Size of the SVSC
11.	Specialization and Facility Equipment of the SVSC

Taking into consideration the factors 5, 6, 7, 8 and 9 during the maintenance planning activity allows the availability of vehicles of the most suitable construction-operation group in the state "ready for operation" in the necessary timeframes for transportation process realization. It affects better cargo capacity utilization by performed transportation volume, which has an influence on the increasing energy efficiency.
For ensuring a rational number of vehicles necessary for transportation process, it is required to take into consideration the factors 4, 5, 9, 10 and 11.
Taking into consideration the factors C_1, C_2 and C_3 has a direct influence on reduction of maintenance costs.
In order to achieve effective maintenance planning, managers should respect all relevant factors while making a decision of selection a suitable SVSC in the region where the planned maintenance work on vehicle will be realized.
Defined factors represent a good basis for the development of a multiple criteria decision-making model for the selection of SVSC in the environment, within maintenance planning.

5. Conclusion

Effective maintenance planning plays a significant role for achieving defined objective of the observed companies. For effective maintenance planning, managers should take into jointly considerations the requirements of transportation process, vehicle maintenance process, as well as environment.
During the maintenance planning activity, managers have to make a decision of selection the locations for maintenance work realization, among others. According to conducted study in 14 companies in Serbia, 8 companies don't have their own maintenance facilities, i.e. they don't have their own workplaces for performing the maintenance interventions on vehicles. In this respect, managers often make a decision on the selection of suitable specialized vehicle service centers (SVSCs) in the region where planned maintenance work on vehicles will be realized.
However, the mentioned decision is influenced by different factors. In order to define the relevant factors influencing mentioned decision, a survey was conducted. Based on conducted survey, managers have to pay more attention on 11 relevant factors while making decision on selection a suitable SVSC in the region. Respecting the relevant factors by managers, fleet maintenance planning is more effective which contributes to the achievement of defined objective of observed companies.
Further research will focus on development of a multiple criteria decision-making model for the selection of SVSC in the region.

Acknowledgment

The research in this paper has been realised within the project TR36027 named: “Software development and national database for strategic management and development of transportation means and infrastructure in road, rail, air and inland waterways transport using the European transport network models” supported by the Ministry of Science and Technological Development of the Republic of Serbia.

References

Ashayeri, J.; Teelen, A.; Selen, W. 1996. A production and maintenance planning model for the process industry, *International Journal of Production Research*, 34: 3311-3326.

Brandolese, M.; Franci, M.; Pozzetti, A. 1996. Production and maintenance integrated planning, *International Journal of Production Research*, 34: 2059-2075.
BS3811. 1984. *British Standard Glossary of Maintenance management terms in terotechnology*. British Standards Institution. UK.
Dhillon, B.S. 2002. *Engineering Maintenance: A modern approach*. CRC Press LLC. USA.
Gits, C. 1994. Structuring maintenance control systems, *International Journal of Operations and Production Management*, 14(7): 5-17.
Johnson, D. 2002. *Principles of Controlled Maintenance Management*. The Fairmont Press, Inc. USA.
Kamakat, F.; Schipper, L. 2009. Trends in truck freight energy use and carbon emissions in selected OECD countries from 1973 to 2005, *Energy Policy*, 37: 3743-3751.
Mobley, R.K.; Higgins, L.R.; Wikoff, D.J. 2008. *Maintenance Engineering Handbook*. The McGraw-Hill Companies, Inc. USA.
Momčilović, V.; Papić, V.; Vujanović, D. 2007. Quality of the Fleet Maintenance Management: A Factor Influencing Sustainable Development. In P*roceedings of the International Congress "Transport Science & Technology Congress"*. ISBN: 978-80-01-03782-9. Prague.
Ruzzenenti, F.; Basosi, R. 2009. Evaluation of the energy efficiency evolution in the European road freight transport sector, *Energy Policy*, 37: 4079-4085.
Vujanovic, D. 2013. *Contribution to the Development of the Vehicle Fleet Maintenance Management. Doctoral Dissertation.* University of Belgrade, Faculty of Transport and Traffic Engineering. Original on Serbian. Serbia.
Vujanović, D.; Mijailović, R.; Momčilović, V.; Papić, V. 2010. Energy efficiency as a criterion in the vehicle fleet management process, *Thermal Science*, 14(4): 865-878.
Vujanović, D.; Momčilović, V.; Bojović, N.; Bunčić, S. 2013. Integrated Management Of The Vehicle Fleet Maintenance Process. In *Proceedings of the International Conference "Science and Motor Vehicles 2013"*. ISBN 978-86-80941-38-7. Belgrade.
Vujanović, D.; Momčilović, V.; Bojović, N.; Papić, V. 2012. Evaluation of vehicle fleet maintenance management indicators by application of DEMATEL and ANP, *Expert Systems with Applications*, 39: 10552-10563.

EFFECTIVENESS OF COMMUNICATION TOOLS IN ROAD TRANSPORTATION: NIGERIAN PERSPECTIVE

Jacob Adedayo Adedeji[1], Samuel Olugbenga Abejide[2],Mohamed Mostafa Hassan[3]
[1,2,3] *Sustainable Urban, Roads and Transportation (SURT) research Group, Central University of Technology, Free State, South Africa.*

Abstract: Continuous increase in death toll as a result of road accident is at an alarming rate. Recent World Health Organization (WHO) global annual report estimated that about 1.25 million people die in road crashes and Africa region as the highest contributor. This traffic fatality rate has, however, been associated with poor roads condition, drink-driving, over speeding, violation of traffic rules, and careless attitude of the road users. Over the years, various measures such as rehabilitation of poor roads and traffic regulations …etc., has been put in place to avert this predicament but the reverse is the case as death toll through road accident increases by years. Additional measures also include the use of traffic communication tools. Although various communication tools exist on the road, this ought to guide the road users and in a way avert the dangers upcoming; however, this is not the case. In Nigeria, various studies have been conducted to this regards but little or no attention is given to the road marking as a communication tool, thus, these three question remains for Nigeria road network; (1) Do these tools (especially, road marking) exist on roads where accidents are frequent? (2) Are these tools effective? (3) What is the understanding of the road users of these tools? Therefore, this study pertains to the effectiveness of the communication tools in road transportation by considering the Nigeria road features and views of the road users. Results show that the drivers have a good knowledge of these traffic communication tools but on an average of 92%, the road marking sampled are not available on the roads and have in one way or the other contributed to the fatality rate experienced. There is a need for stakeholder's interventions which include regular funding and schedule for routine maintenance with more focus on road marking.

Keywords: traffic fatality, traffic communication tools, road marking, traffic safety, Nigeria roads.

1. Introduction

1.1. Traffic Fatality Rate

Globally, road traffic crashes are a leading cause of death and the main cause of death among those aged 15 – 29 years (Agbonkhese et al., 2013; WHO, 2015). Traffic crashes have been blamed on poor roads condition, poor maintenance culture, drink-driving, over speeding, violation of traffic rules, and careless attitude of the road users. Considering the magnitude of death caused by traffic crashes, which is estimated at 1.25 million people per year over the last seven years, it was considered as one of the sustainability development goals. The goal's target is to reduce road traffic death and injuries by 50% by the year 2020 (WHO, 2015).

In view of this, various measures such as rehabilitation of poor roads, implementation of new traffic regulations, and the invention of traffic communication tools (such as; traffic signs, road marking, and traffic signals) were put in place. These measures have improved road safety to some extent. Nonetheless, the measures on global level didn't reduce the predicament rather it only place it on a flat terrain (WHO, 2015), yet the in case of Nigeria, it is on the increase (Adedokun, 2015; Odeleye, 2000; Ezenwa, 1986). As a result, all of these measures have been receiving an improvement in a way to meet up with the aforementioned sustainability development goal. Hitherto, little or no results have been achieved despite the improvement. Focusing on the aspect of traffic communication tools; which should serve as information dispersal to the road user, this information ought to guide the road users and in a way avert the dangers upcoming.

Although some of these tools exist on roads yet, their impact are not felt. Thus, these three question remains for Nigeria road network; (1) Do this tool (especially, road marking) exist on roads where accidents are frequent? (2) Are these tools effective? (3) What is the understanding of the road users of these tools? Therefore, the objective of this study pertains to the effectiveness of the communication tools in road transportation by considering the Nigeria road features and views of the road users.

1.2. Death Toll in Nigerian Roads

Nigeria road network is the largest in West Africa and the second largest in the Sub-Saharan Africa (Okezie, 2013), with an estimate of approximately 200,000 km in length; where 17% is owned by the federal, 16% state and the remaining owned by the local government (Nnanna, 2003). Likewise, Nigeria has a total vehicle population of 10 million vehicles. However, only 19% of the total road network is in good condition while others are either in fair or bad conditions. The fair and bad conditions have contributed greatly to the death toll rate in Nigeria, such that Nigerian road is rated second most deadly road in the world (WHO, 2015). Additionally, according to a report from WHO, Nigeria was adjudged the most dangerous country in Africa with 33.7 deaths per 100,000 population every year (Adedokun, 2015).

[1] Corresponding author: jadedeji@cut.ac.za

However, the problem of traffic fatality in Nigeria is not a new development as Ezenwa (1986) reported on the increasing trends in fatality rates for a period of ten years (1974 – 1983). In the report, within those periods, the number of accidents increased by 10.4% and injured cases increased by 43%. This trend, however, is not capsizing but rather on the increase (Odeleye, 2000), this is evident as recent report show that; 6,450 Nigerian lost their lives in traffic accident and also between 2009 - 2013, the size of small European city population (30,435 people) were killed in traffic fatality on Nigerian roads (Adedokun, 2015). Overall, based on best conservative estimated data, Nigeria is a country with a serious and growing road accident problem and about the worst in the world.

The major contributors to this traffic fatality rate on Nigerian road are, however, similar to those of the rest of the world. Yet, these contributors on a broader note can be categories under some basic factors such as; vehicle operator factors or driver factors, vehicle factors, road condition factors, and environmental factors (Bun, 2012; Agbonkhese et al., 2013). Although most safety studies concluded that driver factors (or human error) are the main cause of accidents (Agbonkhese et al., 2013) yet, it is not the only cause but rather other sources contribute to this factor.

Thus, various measures have been put in place such as; traffic regulation to solve the issues around vehicle operator factors, vehicle factors have also been tackled by some traffic regulations and improvement in the design of the vehicles such as anti-collision sensor, and little or nothing can be done with regards to the environmental factors as these concerns nature and in most cases beyond human control. However, the issue around road condition factors is way behind in resolving the fatality in Nigeria, as most Nigerian roads are still in fair or bad condition. Withal, even the ones in good condition still lack communication tools which as further contributed to the increase in fatality rate (Olaifa, 2013).

2. Traffic Communication Tools

According to Mathew and Krishna Rao (2007), road communication tools or traffic control device is a medium used for communicating between traffic engineer and road users, or mechanisms installed, placed or drawn on road or roadsides by the traffic engineers to communicate certain information to the road users. Furthermore, they are used to provide information to regulate, warn, and guide the road users in a traffic system (Ogunmola, 2013). Some of these tools include; traffic signs, road marking, traffic signals, and parking controls.

Furthermore, communication tools are usually the combination of linguistic and non-linguistic elements (Ogunmola, 2013) and are very important in reducing conflict and collision between the road users and road mishap; thus, their use is not an option to ignore. On the other hand, there is a need for the road users to properly understand these tools and strictly in vive the habit of obeying these tools (Agbonkhese et al., 2013). However, it must be noted that before the installation or positioning of communication tools takes place it should satisfy one or more of the following requirement such as; fulfilling a specific need, commanding attention from users, simple and should convey clear message, and providing adequate time for proper response (Mathew and Krishna Rao, 2007).

In accomplishing the task set before the traffic communication tools, there are various characteristics which need to be put in place for this mechanism to work. These characteristics include; Colour (commonly red, green, yellow, black, blue and brown), Shape (Circular, triangular, rectangular and diamond), legend (Symbols) and Pattern, thus, consistency is of concern as these help the road users to identify them easily (Kadiyali, 1987; Mathew and Krishna Rao, 2007). However, this is based on the fact that these mechanisms recognize the limitation of human (road users) involved, this talk more of the eyesight. Overall, it can be said that most traffic signs available abide by these requirements yet, their maximum impact on the road are not felt but is this the case of Nigerian Road?

2.1. Safety Feature

Traffic communication tools converse safety categorically in three main ways, which are; regulatory signs, warning signs, and informative signs. In-depth explanations on these categories are available in studies Horberry et al., (2004), and Olumide and Owoaje (2016). The various examples of communication tools aforementioned mostly fall under any or all of these three categories except with the exceptional case which is the work zone signs (Mathew and Krishna Rao, 2007). In Nigeria, the importances of these tools are understood such that; in Nigeria road safety strategy 2012, traffic communication tools are one of the strategic goals in improving road infrastructures (Federal Ministry of Works, 2013).

Globally, various researchers (Hulberty et al., 1979; Stokes et al., 1995; Makinde and Opeyemi, 2012; Ogunmola, 2013; Makinde and Oluwasegunfunmi, 2014) have conducted research on the effectiveness of these communication tools. According to Hulbert et al. (1979) and Stokes et al. (1995) in the USA and Kansas respectively, the road users basically misunderstood these tools. In Nigeria, studies showed that these tools are effective in their capacity but the Nigerian road users do not pay attention, rather these tools are seen as mere decorations on the roads (Ogunmola, 2013; Adeboye et al., 2014). Overall, it was, however, noticed that most of the studies concerning Nigeria are centered on the tools such as; traffic signs and signals, with little or no attention given to road marking as a traffic communication tools, thus road fatality continues to increase (Adedokun, 2015). Although the Highway Code of Nigeria entails the road marking as one of the major traffic communication tools, yet little study have put them into consideration.

2.2. Necessities of Road Marking

Speed mitigation devices include signage, road markings, and variable message systems, typically placed in advance of an upcoming hazard with the aim of initiating a change in driver behavior. In particular, signage and markings are widely used for the purposes of explaining road layouts and hazards because of their relatively minor costs in comparison to altering existing geometric layouts (Martindale and Urlich, 2010). Road marking, however, is any kind of device or material that is used on the road surface in order to convey official information. These markings make a vital contribution to safety by clearly defining the path to be followed and are used as communication tools on paved roadways to provide guidance and information to the road users (Federal Ministry of Works, 2013; Ozelim and Turochy, 2014; Rehman and Duggal, 2015).
Road markings can either be mechanical (cat's eye, botts' dots, rumble strips and reflective markers), non-mechanical (paintings) or temporary in nature. As in other communication tools, road markings should be uniform in order to minimize confusion and uncertainty about their meaning and efforts exist to standardize such markings across borders (Mathew and Krishna Rao, 2007; Rehman and Duggal, 2015). However, there are different types of road marking which include; longitudinal marking, transverse marking, arrow marking, oblique parallel lines, word marking, …etc (Federal Ministry of Works, 2013). Additionally, as aforementioned road markings can fall in all the categories of communication tools such as regulatory signs, warning signs, and informative signs.
In the aspect of regulatory signs, the stop paint marking (Figure 1a) at the end of an intersection communicate to the road users (motorists) to stop for a while and observe other vehicles before progressing. Additionally, road marking act as a warning sign in the case of rumble strips (Figure 1b) (also known as sleeper lines) serve as noise generators, also attempts to wake a sleeping driver or alter a driver to various upcoming hazards both by sound and the physical vibration of the vehicle. Transverse road markings as defined by Martindale and Urlich (2010) are used to assist in raising driver awareness of risk through perceptual optical effects, thus encouraging drivers to reduce their speed in anticipation of an upcoming hazard. Overall, road marking alters the road users with information such as the common zebra crossing line, which gives the pedestrians right of way as soon as it is stepped on. In addition, a study based on the USA over a period of twenty years has shown that road markings can reduce fatality by 13% (FHWA, 1994 cited in Grosskopf, 2001).

Fig. 1.
Road Marking (A) Stop paint marking and (B) Rumble strips (Pratt, 2015)

In South Africa, road markings are used on all surfaced roads (Grosskopf, 2001) however, this is not the case in Nigeria as the usage of road marking on roads is still lacking, although after the completion of newly constructed roads, they are mostly marked with road marking such as; solid white line, white broken line, single solid yellow line, lane direction change line, stop marking …etc. Nevertheless, the road markings on the existing ones are poorly maintained (Odeleye, 2000) and thus, the markings fade off and the roads are left without markings. Thus, as a result of their unavailability on most Nigerian roads, the road users do not put them into consideration when available rather, these markings are seen as mere road ornaments by Nigerian road users (Ogunmola, 2013; Adeboye et al., 2014). While on the contrary, because of their available on South African roads the drivers have become so accustomed to them that they tend to react to them without really thinking (Grosskopf, 2001).
Furthermore, in the case of Nigeria most researchers (Makinde and Opeyemi, 2012; Makinde and Oluwasegunfunmi, 2014) have blamed the lack of understanding the traffic signs and communication tools on the education level, yet Akpan et al. (2015) argues that educational background does not seem to correlate with the understanding of and compliance with road traffic signs. Overall, the studies further argue that these tools are too simple not to be understood by a layman or an illiterate; however, these tools seem not to be available on Nigerian roads (Figure 2), despite their enormous contribution to traffic safety.

Fig. 2.
State Road in Nigeria without road markings (Photo taken 29-01-2016)

Charlton and Baas (2006) published a study that evaluated speed change or speed maintenance methods to alter driver behavior, particularly to reduce their approach speeds to a hazard. In Nigeria, the recent security measures (Military checking point stops) taken to screen traffic users on roads in the saga of *Boko Haram* has rather rendered death to some lives than good due to poor visibility of the road blocks sign as well as the approach distance to road blocks in other to alert the driver speed to slow down. Furthermore, speed reduction signals and driver communicating devices are lacking on the Nigerian roads. For example an approach to a roundabout somewhere in the north eastern part of Nigeria has no approach caution signal to a roundabout (Figure 3).

Fig. 3.
Approach to a roundabout without any signal or marking device (Photo taken 29-01-2016)

3. Methodology and Data Collection

3.1. Description of the Study Area

The study was conducted in Nigeria with major emphasis on the North Eastern region since it is a major road mostly challenged by security hazards where both road users and pedestrians have high illiteracy mentality (UNESCO, 2012). Additionally, based on a recent report on traffic fatality in Bauchi state; 123 persons were killed and 1378 were injured in the year 2015, this is without the inclusion of the last three months which are more noted for traffic fatality (Udodiong, 2015). According to a study on causes of road accident in Bauchi state by Yero et al. (2015), the major causes of road accidents include; tire burst, fatigue, obstruction on roads, night journey, loss of control, speed violation, dangerous driving, bad roads, use of phone, and dangerous overtaking. However, it is worthy to note that speed violation and bad roads are the leading contributors to these accidents.

On the bad roads aspect, this has been attributed to limited road signs on the roads. For instance road, signs such as zebra crossings, playgrounds …etc., were unsatisfactorily marked and even lacking at some appropriate places like approach to schools, roundabouts, market areas etc. Most of the communities along the route were denied some useful road signs. The few road signs available are not visible to motorists and pedestrians. Motorists and pedestrians find it difficult to move safely within these areas. Furthermore, because of the busy nature of vehicles on the road, bikers, people especially children and aged found it difficult to cross the road. There is always heavy overcrowding of vehicles and pedestrians on the route.

3.2. Data Collection

The approach used to collect data involved the use of questionnaires defined by sample size specifying a given margin of error which will justify the population size of the total road users and provide a confidence interval of judgment (Gray, 2013). The method used in this research involved the use of questionnaires administered and completed by commercial drivers. Two hundred questionnaires were distributed amongst drivers in various inter-city motor parks in Bauchi, Jos and Gombe viz-a-viz Bauchi-Jos Park, Bauchi-Gombe Park, Bauchi-Yola Park and Bauchi-Kaduna Park and Yankari Park. The questionnaire used was made up of three sections; the first section classifies the personal experience of the drivers, the second section classifies the driver’s opinion and views based on road markings and the third section on traffic signs and signals. The first section was designed to give detailed information about the driver’s bio-data and personal experiences such as the age, gender, and educational background, how well they comprehend the traffic signs and signals as well as the road markings etc. The second section gave information about the availability and type of road markings present on the federal roadways …etc. while the third section assessed the understanding of traffic signs and signals by the drivers. The third section had fifteen multiple choice questions of different traffic signs made up of five warning signs and ten regulatory signs.

4. Results and Discussions

4.1. Demographic Characteristics of respondents

The study indicated that all the respondents (90%) were males and 10% females; this is because driving is a male dominated activity within the north-eastern route drivers. It was observed that females who drive normally do not drive long distances except for few and most females normally drive within the towns or cities. Most of the drivers (80%) interviewed were in the age range of 18 - 35 years (Table 1). The driver’s interviewed were all above the 18 years mandatory driving age in most African countries. As, results from another study indicated that very young drivers (under 19 years) and elderly drivers (over 54 years) face difficulties in understanding and recognizing traffic devices such as road signs (Al-Madani, 2000). The drivers interviewed were educated to some extent, as results show that majority of them (75%) were Junior and Senior high school graduates (Table 2). This implies that the respondents could easily read and write which is a basic requirement for obtaining a driving license in Nigeria. Thus, in this study, it is assumed that all respondents would understand road signs since they have driving licenses and accordingly have passed both the oral and written examinations for obtaining a driving license.

Table 1
Age Range of Respondents

Age of respondents	**Percentage (%)**
18 – 34	80.0
35 – 59	15.0
60 – and above	5.0
Total	100.0

Table 2
Educational level of respondents

Educational Level	**Percentage (%)**
Primary	60.0
Secondary	25.0
Graduate	5.0
Not Educated	10.0
Total	100.0

4.2. General Remarks on Road Signs and Markings

Knowledge of road signs and markings is not only a factor for road accident prevention. However, the application of the knowledge is a key to the essence of these communication tools. This is because road signs and markings convey messages in terms of words or symbols. Signs are, therefore, essential where special regulations apply at specific places or at specific times, where hazards are not self-evident (Al-Madani, 2000). In this study, result indicated that 95% drivers have some level of knowledge concerning road signs and markings while 5% don’t. The interviewed drivers had different driving experiences with the majority of them (45%) having over 6 years driving experience, especially the commercial bus drivers and this shows that they were not novice drivers. It also implies that they have higher class driving licenses and thus, they should comprehend road signs and markings better.

According to Brachacki et al. (1995), year of driving experience helps in proper identification of road signs. Furthermore, Al-Madani, (2000) observed that there exist significant differences between novice and experienced drivers in observing and understanding road signs. This was also confirmed with the exception of drivers with over 10 years of experience (25%) comprehend significantly better than less experienced drivers (Al-Madani & Al-Janahi, 2002). The drivers interviewed belong to various drivers' unions in exception of 10% private car drivers and 10% truck drivers. The unions include the National Union of road Transport Workers (NURTW) (30%), and Bauchi Co-operative Commercial Driver union (70%).
The result also indicated that the common road sign was the speed bumps; 100% of the drivers observed that the roads were in very poor condition due to reduced shoulder and excessive increase in speed bumps on the federal highway resulting in increasing mortality growth. Thus, according to the drivers majority of the road markings (average 91.7%) were not available on the roads as well as the road signs except for few as seen in Table 3.

Table 3
Road Marking Survey

Road Marking	**Available**	**Percentage**	**Not Available**	**Percentage**
Solid White line	60	30	140	70
Single Yellow Line	10	5	190	95
Double Solid Yellow Line	0	0	200	100
White Broken Line	60	30	140	70
Yellow Broken Line and Solid Line	0	0	200	100
White Line-Stop Line	0	0	200	100
Pedestrian Crosswalk	0	0	200	100
Yellow Painted Island	0	0	200	100
Lane Direction Change Line	20	10	180	90
Average	16.7	8.3	183.3	91.7

4.3. Recognition and Application of Road signs and Markings

The ability of drivers to recognized road signs and apply them are the main contributing factors in reducing potential dangers associated with road usage. According to the majority of drivers (90%), mentioned that most of the accidents occurred in communities along the route. However, they could not link it to the negligence of road signs but the occurrence of accidents in communities especially knocking off pedestrians resulted from the reduced shoulder and sudden breaking speed on approach to speed bumps negotiation; knocking down pedestrians and even running into residential buildings close to the roads. This is because driving within a speed limit in town (< 50 km/hr.) when followed should allow drivers to control their vehicles. Encountering road signs about 100 m ahead before seeing the signpost signal drivers to prepare adequately and comply with the sign.

4.4. Challenges of Traffic Communication Tools Along the Routes

Road users face some level of challenges in conforming to the road signs and markings. The result from the study indicates that some of the road signs were covered with leaves of trees along the edge of the road and some have faded off due to the wearing of the paint used. Therefore, drivers could not see what situation is being displayed on the road sign. More so, the conspicuity of some road signs was questionable, as they were blurry and not easily recognizable. In addition, reflectivity, size and placement of road signs were some challenges and the respondents assert that some of the sign posts were not reflective in the dark. The standard guideline for placement of sign post is about 100 m from the situation being shown. Some drivers were of the view that, some road signs were too close to the situation. These situations even pose a risk to them since they normally drive into the situation without any conscious preparedness.

4.5. Road Safety Interventions

Road safety challenges in developing countries such as Nigeria are enormous. However, practical and effective interventions can be implemented to reduce road safety menace. Interventions such as wearing a seatbelt correctly can reduce the risk of road fatalities. Actions such as training of drivers on road safety should be coordinated among the stakeholders for effective results. Additionally, adequate fund should be set aside for routine maintenance which should encompass the repainting of the road markings. Overall, there should be a strong political will from the government for enforcement of road safety measures and capacity of drivers should also be built for the sustenance of interventions.
In addition, it is paramount for all road owning agencies (which in the case of Nigeria includes the federal, state and local governments) to devise a cyclic process for maintenance/ repairing of the road markings, according to their time cycle. Overall, the following guides can help in improving the conditions of road marking on Nigeria roads; firstly, ascertain the total length of road markings to be maintained and this can be done by each of the road owning agencies in Nigeria. Through the projected length, the cost of maintenance can be estimated. Secondly, the quality of the paints to be used must be according to the international recommended standard and the newly improved materials which

improved nighttime visibility should be considered. Thirdly, the function of each road marking must be checked if effective or not and finally, the specification standard of the application must be adhered to as this talk more about quality control. Once these guidelines are put in place one should expect a functional and safety enhance road markings on Nigeria roads.

5. Conclusions

Road signs and markings are very important traffic regulator devices. Neglecting road signs and markings pose potential dangers to both drivers and pedestrian. Different road signs and markings are identified along the route examined the majority without posted notices. Hump ridge ramps are dominant among the road situations for controlling speed in town, as it is more effective than the speed limit warning sign post. However, drivers are aware of the road signs and their importance but most of the drivers do not make any conscious effort to abide by the road signs. Along the route examined, some of the road signs are not conspicuous, not reflective enough to catch the eyes of drivers and their placement were covered with objects and defaced. Thus, the roadsides should be frequently cleared about 3 meters from the road.

Furthermore, the stakeholders involved in road sign designs and traffic regulations such as the Federal Highway Authority should be adequately resourced for the maintenance of road signs along the route and increase the length of the shoulder. In addition, symbolic road signs are easily remembered thus proper placement of these signs within the cities and travel route should be done to reduce mortality rates.

References

Adeboye, G.; Dada J.; Ojonugwa, F.U. 2014. Why Many Nigerian Road Users Ignore Traffic Signs. Available from Internet: <http://leadership.ng/features/391982/many-nigerian-road-users-ignore-traffic-signs>.

Adedokun, A. 2015. Road Accidents in Nigeria, Analysis and Discussion. Available from Internet: <http://omojuwa.com/2015/07/road-accidents-in-nigeria-analysis-and-discussion-by-adeyemi-adedokun/>.

Agbonkhese, O.; Yisa, G.L.; Agbonkhese, E.G.; Akanbi, D.O.; Aka, E.O.; Mondigha, E.B. 2013. Road traffic accidents in Nigeria: causes and preventive measures, *Civil and environmental research*, 3(13): 90-99.

Akpan, U.U. Nsikan Senam, N.; Elijah, P.P. 2015. The Communicativeness of Road Traffic Signs in Uyo, Akwa Ibom State of Nigeria, *International Journal of Education and Research*, 3(2): 685-708.

Al-Madani, H. 2000. Influence of drivers' comprehension of posted signs on their safety-related characteristics, *Accident Analysis and Prevention*, 32(4): 575–581.

Al-Madani, H.; Al-Janahi, A.R. 2002. Assessment of drivers' comprehension of traffic signs based on their traffic, personal and social characteristics, *Transportation Research Part F: Traffic Psychology and Behavior*, 5(1): 63-76.

Brachacki, G.W.Z.; Nicolson, I.R.; Fawcett, J.A. 1995. Impaired recognition of traffic signs in adults and dyslexia, *Journal of Learning Disabilities*, 28(1): 297-301.

Bun, E. 2012. Road Traffic Accidents in Nigeria: A Public Health Problem, *AFRIMEDIC Journal*, 3(2): 34-36.

Charlton, S. G.; Baas, P. H. 2006. *Speed change management for New Zealand roads (No. 300)*. Waterloo Quay, Land Transport New Zealand, Wellington, New Zealand.

Ezenwa, A. O. 1986. Trends and characteristics of road traffic accidents in Nigeria, *Journal of the Royal Society for the Promotion of Health*, 106(1): 27-29.

Federal ministry of Works. 2013. *Highway manual part 1: Design – Volume VI: Road traffic signs and road markings,* FMW, Abuja, Nigeria.

Gray, D.E. 2013. *Doing research in the real world*, Sage, London, UK.

Grosskopf, S.E. 2001. For safety's sake, let's do road marking quality control. In *proceedings of the 20th South African Transport Conference South Africa*.

Horberry, T.; Castro, C.V.; Martos, F.; Mertova, P. 2004. *An introduction to transport signs and an overview of this book*. In Castro, C.; Horberry, H. (Eds.), The Human factors of transport signs, CRC Press, Boca Raton, FL, U.S.A.

Hulbert, S.; Beers, J.; Fowler, P. 1979. *Motorist's Understanding of Traffic Control Devices*, American Automobile Association (AAA), Foundation for Traffic Safety, Falls Church, VA., U.S.A.

Kadiyali, L. R. 1987. *Traffic engineering and transportation*, Khanna publishers, New Delhi, India.

Makinde, O.O.; Oluwasegunfunmi, V. 2014. Comprehension of Traffic Control Devices amongst Urban Drivers-A Study of Ado-Ekiti, Ekiti State, Nigeria, *European Journal of Engineering and Technology*, 2(1): 9-19.

Makinde, O.O.; Opeyemi, D. A. 2012. Understanding of traffic signs by drivers–A case of Akure city, Ondo State, Nigeria, *ARPN Journal of Science and Technology*, 2(7): 608-612.

Martindale, A.; Urlich, C. 2010. Effectiveness of transverse road markings on reducing vehicle speeds October 2010. *NZ Transport Agency research report*, 423(4).

Mathew, T.V.; Krishna Rao, K.V. 2007. Chapter 36: Traffic signs. Available from Internet: <http://nptel.ac.in/courses/105101008/28>.

Nnanna, O.J. 2003. *Highway Maintenance in Nigeria: Lessons from Other Countries*, Central Bank (of Nigeria) Research Department Occasional Paper Series, CBN, Abuja, Nigeria.

Odeleye, J.A. 2000. Towards financing and planning road safety audit operations in Nigeria, *IATSS research*, 24(2): 85-96.

Ogunmola, A.A. 2013. Signs and Symbols as a Communication strategy: A semiotic study of highway codes in Nigeria, *New Media and Mass Communication*, 19.

Okezie, A. E. 2013. A Case for Performance-Based Road Maintenance in Nigeria, *A Paper Presented at the Technical Evening of the Nigerian Society of Engineers*, Port Harcourt Branch.

Olaifa, A. 2013. Crystal Thoughts: The Pandemic Rate of Road Accidents in Nigeria. Available from Internet: <http://www.abiolla.com/2011/06/pandemic-rate-of-road-accidents-in.html>.

Olumide, A.O.; Owoaje, E.T. 2016. Rural-urban disparity in knowledge and compliance with traffic signs among young commercial motorcyclists in selected local government areas in Oyo State, Nigeria, *International Journal of Injury Control and Safety Promotion*, 1-10.

Ozelim, L.; Turochy, R. E. 2014. Modelling Retro reflectivity Performance of Thermoplastic Pavement Markings in Alabama, *Journal of Transportation Engineering*, 140(6): 05014001.

Pratt, M. J. 2015. Navigating Between the Rumble Strips of Your Trucking Business. Available from Internet: <http://www.tailwindtransportationsoftware.com/blog/>.

Rehman, S.A.U.; Duggal, A. K. 2015. Suitability of different material used for Road marking-A Review, *International Research Journal of Engineering and Technology*, 2(2): 622-625.

Stokes, R. W. et al. 1995. *Motorist Understanding of Traffic Control Devices in Kansas*, Final Report No. KSU94-7, Department of Civil Engineering, Kansas State University, Manhattan, KS.

Udodiong, I. 2015. In Bauchi: State government partners with FRSC to address road traffic accidents. Available from Internet: <http://pulse.ng/traffic/in-bauchi-state-government-partners-with-frsc-to-address-road-traffic-accidents-id4447783.html>.

UNESCO 2012. High level International Round Table on Literacy “Reaching the 2015 Literacy Target: Delivering on the promise” UNESCO, Paris, 6-7 September 2012.

World Health Organization (WHO). 2015. WHO Global status report on road safety 2015.

Yero, A.S.; Ahmed, Y.T.; Hainin, R.M. 2015. Evaluation of Major Causes of Road Accidents along North–East Highway, Nigeria, *Jurnal Teknologi*, 73(4): 39-43.

SESSION 9: ROAD TRAFFIC AND TRANSPORT RESEARCH - MANAGEMENT AND POLICY ISSUES

MODELLING WEEKEND TRAFFIC WITH WEATHER CONDITIONS USING VARIOUS EQUATION TYPE AND DIFFERENTIAL EVOLUTION ALGORITHM

Erdem Doğan[1], Ali Payıdar Akgüngör[2], Ersin Korkmaz[3]
[1,2,3] Civil Engineering Department, Engineering Faculty, Kırıkkale University, Kırıkkale, Turkey

Abstract: In weekends, amount of passenger car traffic is usually higher than weekday because of the activity-based traveling on some highways. Forecasting of this traffic, might help to local authorities to take safety precautions decisions on a road segments. This study aims to compose models to forecast weekend traffics using weather conditions and average weekday traffic variables. For this aim, two main models were composed: The Saturday traffic model and the Sunday traffic model. The Saturday traffic model variables are mean weekday daily traffic, maximum temperatures of Saturday and precipitations. The Sunday model is a linear model with only one variable: the predicted traffic values from the Saturday traffic model. In the modeling Saturday traffics, six-month (from January to June) data, which belongs to year 2015 and Ankara–Kırıkkale highway in Turkey, were used and 2014-March data were used for testing the models. The used temperatures were normalized and the precipitations data were involved as logical (0 or 1) inputs in models. To find best equation type for Saturday traffic model, four various equation forms were selected: (1) Linear, (2) polynomial-1, (3) polynomial-2, (4) multiplicative equation from. The linear and polynomial-1 have three, multiplicative has four, and polynomial-2 equation has five coefficients need to be determinate. Differential evolution algorithm was utilized to determinate best fitted values for these coefficients. Performance of the models were calculated using mean square error and coefficient of determination. The model with the polynomial-2 equation has minimum errors for the modelling stage and R^2 value is around 0.80. The model with the polynomial-2 showed the best performance on testing stage (R^2=0.96). These results show that the weekend traffic is related to weather conditions and it can be modeled convenient equation form and differential evolution algorithm.

Keywords: traffic forecasting, weekend traffic, weather conditions, model development, differential evolution, Turkey, Kırıkkale.

1. Introduction

The weather condition has an important effect on road user decision for traveling or not. Therefore, it needs to consider as an input variable in traffic modelling. For example, (De Palma and Rochat 1999) took a poll to understand the users' behavior with respect to transportation issues. The survey results showed that about 40% of respondents thinks that weather conditions have a significant influence on their decisions about traveling. Even if significant amount of traveler decides to not use roads, the road system users are still affected from adverse weather conditions. Therefore, the policymakers need solid strategies to control road systems in such events. Nowadays, advanced traffic management systems (ATMS) are applied to highways to use these strategies (Zhang, Holm, and Colyar 2004) . But these systems need information about traffic variations in future. For this reason, traffic forecasting is an important process to inform road users, ATMS and local government units. These information requirements have been pushing researchers to develop traffic forecasting models.

Some research reported about weather effect on traffic characteristic and user decisions. The first research about the weather and traffic was started with (Tanner 1952). (Hanbali, Rashad M. 1993) studied about snow storm and traffic volume in United Stated. They reported that snow storm might decrease traffic volume up to 56% depend on severity of storm. (Keay and Simmonds 2005) reported that the traffic volume decreases 1.35% in winters and 2.11% in springs. (Kilpellainen and Summala 2007) researched about weather forecast and driver choose about traveling. Their result suggests that prevailing road weather conditions are more dominant than weather forecasts for on-road driving behavior. The other research about the effect of weather conditions are (Andreyl and Olley 1990; Changnon 1996; Hall and Barrow 1988; Ibrahim and Hall 1994; Knapp and Smithson 2000).

The weekend traffic is mostly consist of activity-based travel, therefore it has different characteristics (Chandra R Bhat and Gossen 2004). This phenomenon tends researches to investigate about activity-based travel and demand models (C R Bhat and Misra 1999; Bowman and Ben-Akiva 2000; Hunt and Patterson 1996; Mallett and McGuckin 2000). These researches tried to understand the traveler choice of destination, travel modes, etc. Unlike these researches, this study is trying to develop forecasting model of daily activity based traffic to help policymakers to plan traffic control regulations.

Traffic forecasting models can be categorize into four class (Van Lint and Van Hinsbergen 2012). These are naïve, parametric, non-parametric and hybrid. Naïve model approaches are simple models and estimates future traffic with using historical average traffic data. Parametric approaches are model based techniques and they use mathematical or statistical equations (Wang, Papageorgiou, and Messmer 2006). The non-parametric model approaches utilize intelligent algorithms such as artificial neural networks (Habtemichael and Cetin 2015). On the other hand, hybrid models are implementation of the three mentioned approaches. (Vlahogianni, Karlaftis, and Golias 2014) summarized the most of the traffic models, if reader wants to more information. Most of the traffic forecasting attempts above in literature used time series techniques so they mainly utilized previous forecast results to estimate following traffic.

[1] Corresponding author: edogan@kku.edu.tr

2. The traffic volume and weather data

This study used traffic and weather data of 2014 and 2015. The Republic of Turkey General Directorate of Highways (GDH) has been collecting the traffic volume data at continuous count sites since 2009. The traffic data was taken from highway between Ankara (capital) and Kırıkkale by using GDH data. In the weekends, the passenger-car traffic usually increases because of activity-based travelling in this highway. The accessed data from the count site consist of passenger-car volume between January and June in 2015 and March 2014. Between this time period, 25 average daily weekday traffic (DwdT), daily Saturday traffic (DsatT) and daily Sunday traffics (DsunT) were used to compose the models and March data were used for testing. The fluctuation of mean weekday, DsatT and DsunT via time is given in Fig.1. The daily traffics have a tendency to increase in observed time period.
The daily traffic of the observed time period is given in Fig 1. The DwdT were computed to sum weekdays (Monday to Friday) daily traffic and divide the sum of weekday traffic to number of weekdays. The DwdT is generally lower than DsatT and DsunT has usually highest traffic over observation period.

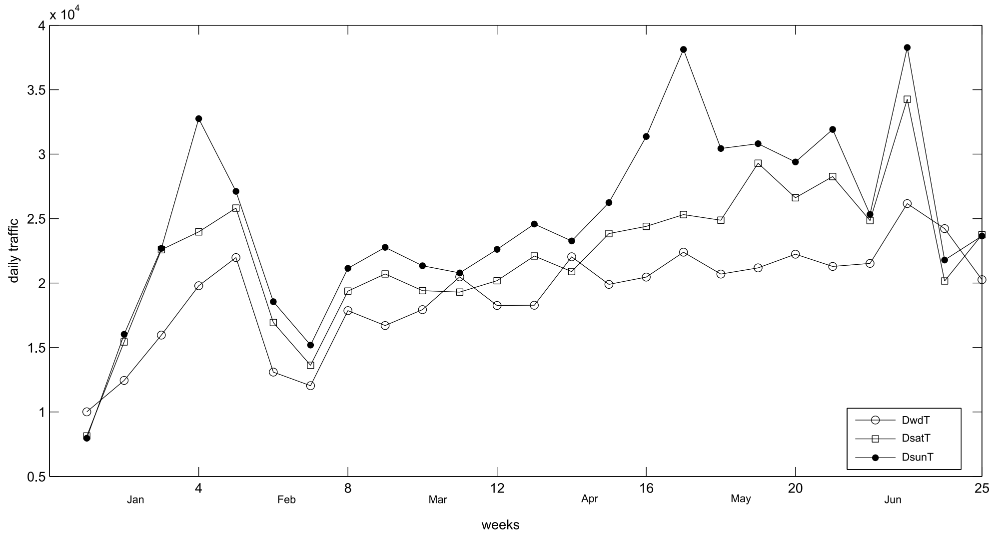


Fig. 1.
Daily (Sat. and Sun) and average daily (weekday) traffics from January to June

The temperature data were taken from (Http://www.havadurumu15gunluk.net/ n.d.). The highest temperature (H-tmp) of Saturdays and weather conditions with daily traffic of each Saturday's is shown in Fig. 2. In the observed time period, there were 11 rainy/snowy Saturday from 25 weekends and the H-tmp variated from -5 °C to 26 °C. The DsatT, the green line in Fig. 2, has tendency of increase and it is also obviously affected from temperature change. In the first 7 weeks the H-tmp mostly under 10 °C and DsatT is highly depended on H-tmp in these weeks as seen from Fig 2. After this 7 weekends period, the DwdT increases with linear trend. The precipitation also affects the DwdT to decrease in some of the weekends. In fig 2, at weekend 17 to 18, the H-tmp seems almost same but DwdT decreases in weekend 18.

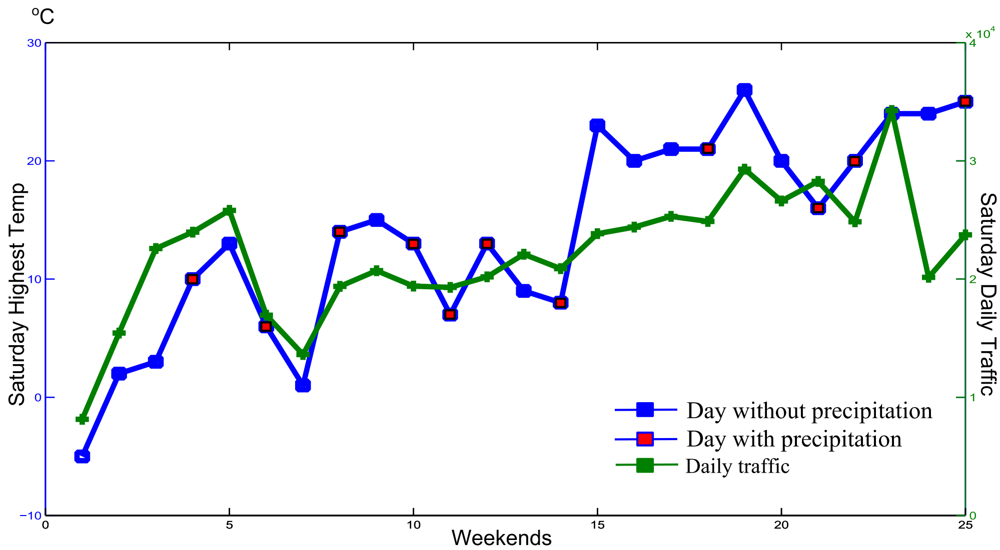


Fig. 2.
The Saturday's daily traffic values with temperatures and weather conditions

$$x_{norm} = \frac{x_{real} - x_{min}}{x_{max} - x_{min}} (x^{upper} - x^{lower}) + x^{Lower} \quad (1)$$

Where;
x_{norm} : Normalized value.
x_{real} : Real value.
x_{min} : Minimum value.
x_{max} : Maximum value.
x^{upper} : Upper value for normalization.
x^{lower} : Lower value for normalization.

The data normalization process simplifies the modelling so the temperature and traffic data were normalized with using Equ.1. For temperature, x_{min} and x_{max} were selected -15 °C and 40 °C; for the daily traffic x_{min} and x_{max} were selected 0 veh/day and 50000 veh/day, respectively. For both temperature and traffic data, x^{upper} and x^{lower} values, were selected 0 and 50000.

3. Weekend traffic forecasting models

Two different models were developed to forecast weekend traffics: The Saturday Traffic Model (SaTM) and The Sunday Traffic Model (SunTM). Four forms of equation were used to develop SaTM: (1) Linear, (2) polynomial-1, (3) polynomial-2, (4) multiplicative equation. In all forms, DwdT, normalized highest temperatures (H-tmp) and the rain/snow condition (RSP) were used as model inputs.

The linear traffic model is given in Equ. 2. There are three coefficients *(x_1, x_2, x_3)* needs to be determined in the model.

$$DsatT = x_1.DwdT + x_2.H - tmp + x_3.RSP \quad (2)$$

The polynomial-1 traffic model is given in Equ. 3. There are one exponential coefficients and two exponent needs to be determined in the model.

$$DsatT = DwdT^{x_1} + H - tmp^{x_2} + x_3.RSP \quad (3)$$

The polynomial-2 traffic model is given in Equ. 4. There are three coefficients and two exponent needs to be determined in the model.

$$DsatT = x_1.DwdT^{x_2} + x_3.H - Tmp^{x_4} + x_5.RSP \quad (4)$$

The multiplicative traffic model is given in Equ. 5. There are two coefficients and two exponent needs to be determined in the model.

$$DsatT = x_1.DwdT^{x_2}.H - Tmp^{x_3} + x_4.RSP \quad (5)$$

The RSP is the logical input and if there is rain/snow, it will take “1”. Otherwise it takes “0”. Therefore, this study did not use exponent with RSP.

The Sunday and Saturday traffic relation is understated from observation of Fig 1, and Sunday traffic consisting mostly return home traffic and it is not affected from weather unless extreme weather conditions. Therefore, the Sunday traffic model (SunTM) were composed with SaTM model estimation with linear equation form as given in Eq. 6. The linear regression was used to determine the x_1 in Equ 6.

$$DSunT = x_1.DsatT \quad (6)$$

Differential evolution (DE) were used to optimize the coefficients and exponents. DE is a heuristic technique for searching optimum parameters of functions (Storn and Price 1995, 1997). DE can give approximate results in non-linear and complex optimization problems. The fundamental steps of DE are initialization, mutation, crossover and selection (Kenneth Price, Rainer M. Storn 2005) and other information were illustrated in Fig 3. The population size (NP), weighting factor (F) and crossover ratio (Cr) are important parameters and they need to be set properly for problems. The F is need to be between 0 and 2, the CR is need to be between 0 and 1. In this study, F and Cr values were determined after a search process. In this process, all possible combination of Cr and F were tried with 0.1 increment. All of the combinations were also tried 30 times to be sure bout not missing the best combination.

Population consisting of D dimensional real-valued vectors. In our study, this vectors consists of the models' coefficients and degrees. The population for the polynomial-1 traffic model is given in Equ 7 as an example.

$$Pop_g = \begin{bmatrix} x_{1,1} & x_{1,2} & x_{1,3} \\ . & . & . \\ . & . & . \\ . & . & . \\ x_{12,1} & x_{12,2} & x_{12,3} \end{bmatrix} \quad (7)$$

The NP selected 4 times of the vector dimension, so there are (NP = 4x3 = 12) vectors used in polynomial-1 DE population (Equ. 7) . DE changes population vectors at each generation (g) with the vector which has better performance than previous vectors.

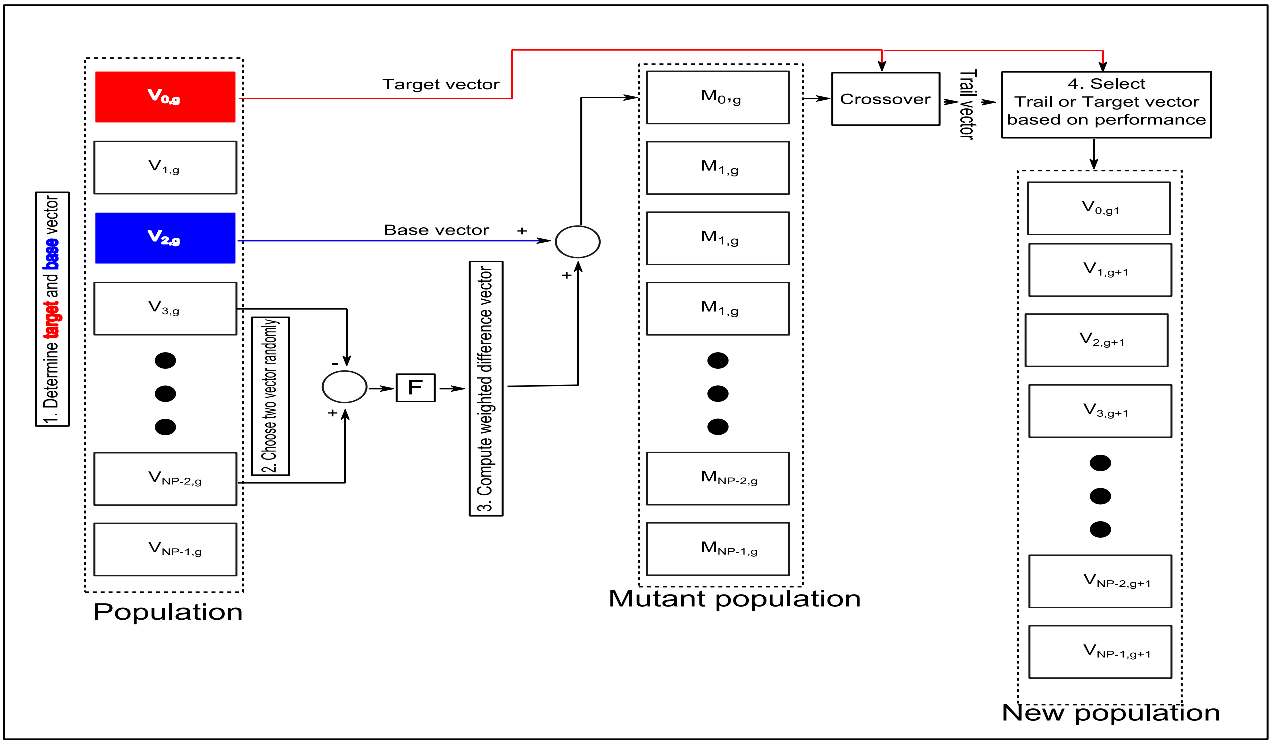


Fig. 3.
Differential evolution steps

4. The results and discussion

The traffic models' coefficients and degrees were given in Table 1. It is being understood from values of x3, x5 and x4 in Table 1 that the snow and rain decrease daily traffic approximately 2000 veh/day in study field. The Polynomial-2 model is given highest R^2 value and it is 0.80. The rest of the models R^2 values were very close to each other and the MSE are also close to each other for these three models as illustrated in Fig 5. The model degrees were settled between -1 and 1. The DwdT coefficient (x_1) is higher than x_2 for the linear model in Table 1.

Table 1
The Saturday traffic models' coefficient and exponents

	R^2	x_1	x_2	x_3	x_4	x_5
Linear M.	0.77	0.9857	0.1666	-2060		
Polynomial-1 M.	0.77	0.9927	0.8463	-2064		
Polynomial-2 M.	0.80	151.34	0.5305	$-7.58.10^7$	-0.965	-2526
Multiplicative M.	0.77	2.2980	0.7297	0.1998	-2066	

The SunTM was developed with linear curve fitting with MS-Excel. The R^2 value is about 0.84 as seen from Fig 4.

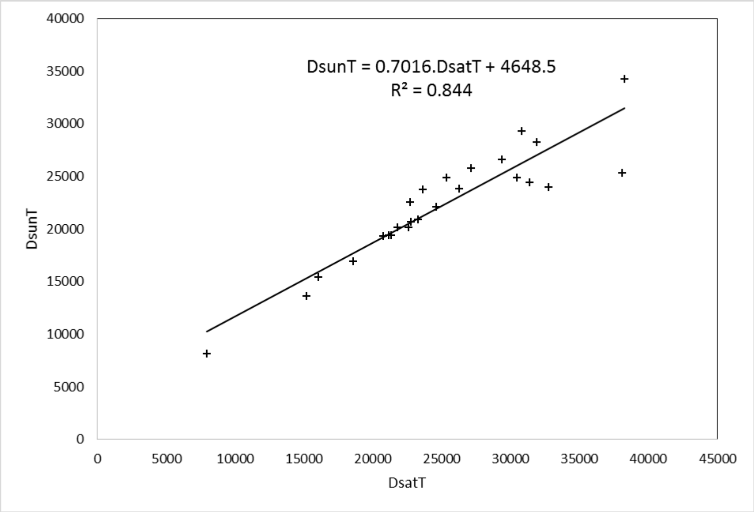


Fig. 4.
R2 value of SunTM

Differential evolution algorithm is powerful optimization technique but it needs to work with proper parameters. The Cr and F values were determined after the trail process. The CR values will be between 0 and 1 and the F values will be between 0 and 2. Therefore all possible combination, with 0.1 step, of F and CR were tried to find the best F and CR value. The results are given in Fig 5 and the best points/point is/are stated with red points. For linear and polynomial-1 model, most of the combinations produced best results and only the combinations near limits produced higher mean squared errors (MSE). The polynomial-2 model produced minimum MSE in CR=0.9 and F = 0.7 among all the models as seen from Fig 5. For multiplicative model, the best results were produced in the area with bounds of CR = [0.7 0.9] and F = [0.5 0.9] but the multiplicative form errors is higher than polynomial-2 model. Therefore, the polynomial-2 model was selected to create SaTM.

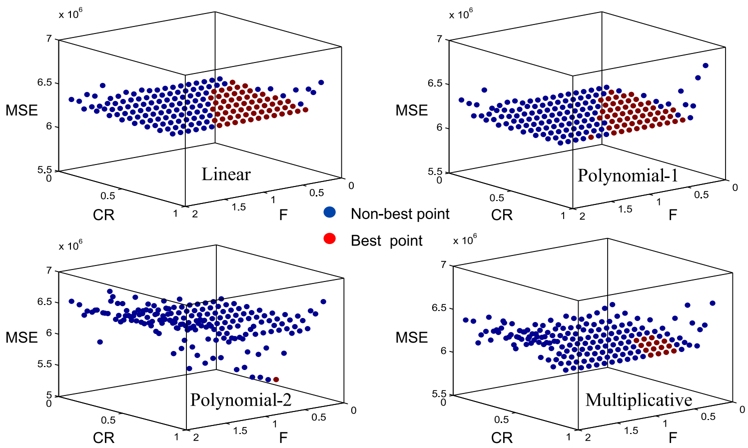


Fig. 4.
The MSE values for CR and F combinations

All models were tested with Marc 2014 traffic values. There were four weekend in Marc 2014 and the estimated and actual daily traffic values are compared using R^2. The linear model, Polinomal-1 and polinomal-2 models gave similar R^2 values and they were about 0.92. The multiplicative model gave best result among the other models and it was 0.95.

5. Conclusion

This study aims to develop weekend traffic forecasting model using weather conditions for Kırıkkale/Turkey. The parametric equations were used in models and DE were utilized to adjust the model coefficients and degrees. Two main type of models were adjusted: The Saturday model and the Sunday model. For Saturday model, four different equation type were considered and the polinomal-2 was showed better performance in Saturday model developing stage. On the other hand, the multiplicative model showed slightly better R^2 value. The Sunday model is a linear model and it has one coefficient and one constants. The variable of the model is the Saturday traffic estimation. These models have enough R^2 values and they are useful for forecasting weekend traffics. The developed models might be used by local traffic units to understand weekend traffic and to take precautions for safety issues. In addition, the ITS and ATMS needs future traffic information to control traffic and to inform road user for safer and comfortable traveling.

Acknowledgements

The authors would like to thank Republic of Turkey General Directorate of Highways for providing traffic data.

References

Andreyl, J.; Richard, O. 1990. Relationships Between Weather and Road Safety: Past and Future Research Directions, *Climatological Bulletin*, 24(3): 123-37.

Bhat, C.R.; Gossen, R. 2004. A Mixed Multinomial Logit Model Analysis of Weekend Recreational Episode Type Choice, *Transportation Research Part B: Methodological*, 38(9): 767-87.

Bhat, C.R.; Misra, R. 1999. Discretionary Activity Time Allocation of Individuals between in-Home and out-of-Home and between Weekdays and Weekends, *Transportation*, 26(2): 193-209.

Bowman, J.L.; Ben-Akiva, M.E. 2000. Activity-Based Disaggregate Travel Demand Model System with Activity Schedules, *Transportation Research Part A: Policy and Practice*, 35(1): 1-28.

Changnon, S.A. 1996. Effects of Summer Precipitation on Urban Transportation, *Climatic Change*, 32(4): 481-94.

De Palma, A.; Rochat, D. 1999. Understanding Individual Travel Decisions: Results from a Commuters Survey in Geneva, *Transportation*, 26: 263-81.

Habtemichael, F.G.; Mecit, C. 2015. Short-Term Traffic Flow Rate Forecasting Based on Identifying Similar Traffic Patterns, *Transportation Research Part C: Emerging Technologies*.

Hall, F.L.; Barrow, D. 1988. Effect of Weather on the Relationship between Flow and Occupancy on Freeways.

Hanbali, R.M.; Kuemmel, D.A. 1993. Traffic Volume Reductions due to Winter Storm Conditions, *Transportation Research Record*, 1387.

Hunt, J.D.; Patterson, D.M. 1996. A Stated Preference Examination of Time of Travel Choice for a Recreational Trip, *Journal of Advanced Transportation*, 30(3): 17-44.

Ibrahim, A.T.; Hall, F.L. 1994. Effect of Adverse Weather Conditions on Speed-Flow-Occupancy Relationships, *Transportation Research Record*, 1457: 184-91.

Keay, K.; Simmonds, I. 2005. The Association of Rainfall and Other Weather Variables with Road Traffic Volume in Melbourne, Australia, *Accident Analysis and Prevention*, 37(1): 109-24.

Kenneth, P.; Storn, R.M.; Lampinen, J.A. 2005. *Differential Evolution: A Practical Approach to Global Optimization*. Springer.

Kilpellainen, M.; Summala, H. 2007. Effects of Weather and Weather Forecasts on Driver Behaviour, *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(4): 288-99.

Knapp, K.; Smithson, L. 2000. Winter Storm Event Volume Impact Analysis Using Multiple-Source Archived Monitoring Data, *Transportation Research Record*, 1700: 10-16.

Mallett, W.; McGuckin, N. 2000. Driving to Distractions: Recreational Trips in Private Vehicles, *Transportation Research Record: Journal of the Transportation Research Board*, 1719: 267-72.

Storn, R.; Price, K. 1995. Differential Evolution-a Simple and Efficient Adaptive Scheme for Global Optimization over Continuous Spaces.

Storn, R.; Price, K. 1997. Differential Evolution–a Simple and Efficient Heuristic for Global Optimization over Continuous Spaces, *Journal of global optimization*, 341-359.

Tanner, J.C. 1952. Effect of Weather on Traffic Flow, *Nature*, 169(4290): 107. http://dx.doi.org/10.1038/169107a0.

Van Lint, J.W.C.; Van Hinsbergen, C.P.I.J. 2012. Short-Term Traffic and Travel Time Prediction Models, *Artificial Intelligence Applications to Critical Transportation Issues*, 22: 22-41.

Vlahogianni, E.I.; Karlaftis, M.G.; Golias, J.C. 2014. Short-Term Traffic Forecasting: Where We Are and Where We're Going, *Transportation Research Part C: Emerging Technologies*.

Wang, Y.; Papageorgiou, M.; Messmer, A. 2006. RENAISSANCE – A Unified Macroscopic Model-Based Approach to Real-Time Freeway Network Traffic Surveillance, *Transportation Research Part C: Emerging Technologies*, 14(3): 190-212.

Zhang, L.; Holm, P.; Colyar, J. 2004. Identifying and Assessing Key Weather-Related Parameters and Their Impacts on Traffic Operations Using Simulation.

EVALUATION OF TRAFFIC CONGESTION AND RE-ENGINEERING SOLUTIONS FOR CENTRAL AREAS OF SOUTH AFRICAN CITIES: A CASE STUDY OF KIMBERLEY CITY

Dillip Kumar Das[1], Mmusho Keetse[2]

[1] *Department of Civil Engineering, Central University of Technology, Free State, Bloemfontein, South Africa*
[2] *Principal Engineering Assistant, Sol Plaatje Municipality, Kimberley, South Africa*

Abstract: Traffic congestion in and around the central business districts (CBD) of South African cities is a major challenge. Apparently, it is engendering undesirable consequences that include impeding vehicular flow, causing vehicular and pedestrian conflicts, escalating travel time, and frequenting vehicular crashes. So, using a case study of Kimberley city in South Africa, this study assessed the causes and degree of traffic congestion on the roads in and around the CBD area; and examined the impact of plausible re-engineering measures to alleviate the challenge. Survey research methods were used to collect data. Land use and urban functions influencing urban movements, road, and traffic scenario data were collected through physical and traffic survey at different selected road sections and junctions of the CBD area by following appropriate survey protocols. Besides, road user perception and travel behaviour survey were conducted among 208 (N= 208) road users by using random sampling process at important nodes of the city. Relevant empirical models were used to assess the causes and level of traffic congestion, and to examine the impact of re-engineering solutions on the current and forecasted traffic scenarios. Findings suggest an appreciable level of traffic congestion is experienced currently in some of the roads of the CBD area and the situation will be aggravated in future, specifically during the peak hours, whereas a number of roads are highly underutilised. Re-engineering solutions such as appropriate traffic assignment and modal split, i.e., traffic diversion ranging between 9.0% and 40.5% from different congested roads and restriction of plying of heavy vehicles on the congested roads during peak hours and assigning them to connected underutilised roads could ease traffic congestion, increase speed and reduce travel time and consequently enable optimal use of the majority of the roads in and around the CBD area of the city.

Keywords: central business district, traffic congestion, level of service, modal split, peak hours, traffic assignment.

1. Introduction

Traffic congestion has been a critical challenge in many cities across the world. It engenders a range of undesirable consequences that include negative economic impacts and environmental pollution (Rao and Rao, 2012; Sorensen et al., 2008; Wang, Gao, Xu, Sun, 2014). Many South African cities suffer from this challenge. Particularly, the central business districts (CBD) of a number of large and medium cities of the country are observed to be affected by the congestion challenges during different periods of the day. Kimberley city of Northern Cape Province of the country is a typical; example. The city, because of its unique physical, spatial, road network, economic characteristics, and requirement of mobility of heavy vehicles in addition to the normal city traffic experience critical traffic congestion challenge in its CBD area, particularly during the peak hours. Consequently, issues such as loss of economic benefits because of increase of travel times of vehicles in mining activities, delay in travel and change of travel pattern of local people for day to day activities, environmental pollution, and higher consumption of fuel and anxiety of people to travel top CBD area during business hours have emerged. In addition, experiences of different policy interventions such as creation of additional road infrastructure, Travel Demand Management measures, reinforcement of public transportation system, congestion pricing, encouragement of non-motorised transportation system, limiting parking facilities, etc., which have been tried in different cities of the world suggest that, these solutions have met mixed successes. Besides, they require creation of infrastructure, enforcement of certain constraints and restrictive measures and change in mobility behaviour, which is sometimes unacceptable by people and also incurs huge investment, making such projects economically unsustainable and socially unacceptable. This warrants acceptable and cost effective remedial measures to alleviate the traffic congestion challenges in the city. However, before evolving remedial interventions, it is necessary to assess the level of traffic congestion and reasons thereof; understand the perspective influence of the solutions that could assist in evolving strategies to meet the challenges. Therefore, the objective of this paper is to explore the causes and degree of traffic congestion on the roads in and around the CBD area; and examine the impact of plausible re-engineering measures to alleviate the challenge. The study was conducted by using Kimberley city of South Africa as a case study. A survey research method and relevant statistical and empirical models were used for the conduct of the investigation. . The study revealed that an appreciable level of traffic congestion is experienced currently in some of the roads of the CBD area and the situation will be aggravated in future, specifically during the peak hours, whereas a number of roads are highly underutilised. Re-engineering solutions such as appropriate traffic assignment and modal split, i.e., traffic diversion ranging between 9.0% and 40.5% from different congested roads and restriction of plying of heavy vehicles on the congested roads during peak hours and assigning them to connected underutilised roads could ease traffic congestion, increase speed and reduce travel time and consequently enable optimal use of the majority of the roads in and around the CBD area of the city.

[2] Corresponding author: ddas@cut.ac.za

2. Literature Review

Traffic congestion occur when traffic is delayed due to the presence of excess number of vehicles on the same portion of the road way at a particular time because the number vehicles trying to use the road exceeds the design capacity of the road (Department of transportation U.S., 2005, p. 1; Link et al. 1999, p. 9). As a result, there shall be long queues of vehicles, vehicles move slower than the normal or "free flow" speeds and at constant start and stop basis. It also results into delay in the overall traffic movement in a road network and the traveller fails move in a desirable manner (ECMT, 1999; Goodwin 2004; Levinson et al., 1997; Lomax, 1990; Lomax, Turner and Schunk, 1997; Taylor, 2003;). The traffic can be recurrent, non-recurrent and of pre-congestion state (Banjo, 1984; Chakwizira, 2007; HCM, 2000).

The reasons for traffic congestion can be grouped into three broad categories, such as, traffic influencing events, traffic demand and physical road features. Traffic incidents, work zones and weather are the traffic influencing events. Traffic incidents include vehicular crashes, breakdowns, debris in travel lanes, events that occur on the shoulder or roadside, etc. A construction activity on the roadway is the example of a work zone. Reduced visibility, bright sunlight on the horizon, presence of fog or smoke, wet, snowy or icy road way are the examples of poor weather. Traffic demand includes fluctuations in normal traffic, such as day to day variability in demand and special events. Physical highway features include road way physical and geometrical characteristics, poor traffic control devices and physical bottlenecks (capacity) of the road (Talukdar, 2013; United States, 2005, pp.1-2). There are several indicators, which are used to assess the level of congestion on the roads. One of the major indicators, which mostly favoured is the total amount of delay encountered calculated across all traffic from the difference between the actual speed encountered and free flow speed (Dft, 2000, 2000b; Dijker, Piet, Bovy, and Vermijs, 1998; Dodgson, Young, and van der Veer, 2002; Grant-Muller, 2005). It was believed to be advantageous in providing a better picture of how changing traffic levels and different policy packages can affect time lost to congestion, although delays are measured purely in terms of vehicle journey time and no allowances are made for differences in occupancy rates, values of time, or for additional factors, such as additional operating or environmental impacts that congestion can generate. Similarly, other simple measures relating to speed are also used to indicate congestion, particularly for a motorway environment (Grant-Muller, 2005). These indicators include mean journey times, variability of journey times, throughput (total number of vehicles per time interval that pass a point on the carriageway), queue lengths, speed differential between lanes and delay per hour/day (Graham and Glaister, 2004; Grant-Muller, 2005; Grant-Muller & Laird 2006; Noland and Polak, 2002). Besides, the congestion reference flow (a quantified measure of congestion for a link -junction must be considered separately) and the level of service (LOS) are other basic congestion measures applied widely in some countries like USA and Scotland, (Highways Agency, 1997; State-wide Planning Scenario Synthesis, 2005).

In the city level, the concentration of trip destinations in a small area – particularly CBD of the cities poses the challenge of providing large transportation capacity in limited physical space, while preserving the historical, political, cultural, economic and environmental heritage/values of the areas. It is evident that a larger share of trips flow to the city centres and they are found to grow exponentially with the city size. Simultaneously, CBDs are characteristically areas of high concentration of activities, and space is scarce. Thus, a dichotomy of high demand for transportation capacity in a geographic environment where space is limited does exist (Das and Keetse, 2015; Lascano Kezic, Durango-Cohen, 2012).

The various approaches such as supply management, land use management and transportation demand management have been resorted to alleviate the challenge (Ceylan and Bell, 2004; Gao and Song, 2000; Meyer, 2003; Stevanovic et al., 2013; Yang and Bell, 1998; Zanjirani Farahani et al., 2013). However, according to critics of this method, majority of the traffic jams are caused by accidents and events – not because of lack of capacity (STPP, 2001), so adding capacity to alleviate the problems becomes controversial on account of induced demand argument and the environmental and health effects of additional travel and land consumption (Gifford, 2005). Besides, supply management methods do little to mitigate congestion caused by non-recurring incidents. Land-use management describes the use of growth management, planning, and zoning to promote local density to encourage transit. Transit oriented development and high-density land use are both examples of this type of management. Similarly, land use management measures are criticized for two major challenges- that increased congestion is created by high-density development, and it takes long time to change land-use patterns and behaviors; they also doubt regarding the connection and causality between the two (Taylor, 2002). Transportation demand management (TDM) strategy institute largely financial incentives and disincentives to encourage motorists to use alternate routes, times and modes, or to defer trips entirely in order to reduce the demand for traffic facilities. TDM measures include congestion pricing, park-and-ride lots, high-occupancy-vehicle lanes, high-occupancy-toll lanes, employer commute option programs, telecommuting, alternative work schedules, and traffic calming measures. Of all the measures, congestion pricing tends to be both most effective and politically legitimate as a funding source (Gifford, 2005); however, due to the cost it places on drivers, it is one of the hardest methods to implement (Bass, 2008).

Besides, meticulous traffic design, use of technology – use of intelligent traffic system, Global Positioning System (GPS), inter vehicle communication and vehicle simulator, and variable message signs approaches are the other ways, which are used to reduce traffic congestion (Alterkawi, 2006; Chen, Yu, Zhang, Guo, 2009; Das and Keetse, 2015; Furth, Muller, 2009; Hardjono, 2011; Salicru, Fleurent, Armengol, 2011; Santos, Coutinho-Rodrigues, Current, 2008; Yin, Lam, Miller, 2004). Efficient vehicle routing, punctuality of routes and diversion of vehicles are also considered as other options to alleviate traffic congestion particularly in the congested urban areas. Although, some research has been done in this area, the focus is limited to a number of prototype problems, and the literature on vehicle routing –

segregation of vehicular traffic (modal split), optimal traffic assignment on different alternative roads and reengineering of the traffic system at the local level, and their impact on the road network – congestion and travel time under the effect of combination of the parameters is scarce (Cordeau, Laporte, Savelsbergh, Vigo, 2007). However, with increased growth of traffic flow, it is crucial to develop cost-efficient policies, which would alleviate traffic congestion and address negative externalities in terms of environmental impact and cost to the economy (Watling, Milne, Clark, 2012; Das and Keetse, 2015).

3. Case Study: Kimberley city

Kimberley City of South Africa was considered as the study area for this study (Figure 1). It is the capital city of the Northern Cape Province of the country and is situated on the latitude 28.7419°S and longitude 24.7719° E. It is known for its diamond mining activities. However, in recent years the economic functions of the city are changing because of the reduced mining activities. The city has a combined urban population of more than 225000 (Census, 2011). It has a total of 48 suburbs, which includes districts and townships and has a designated CBD. The city is connected to various major cities of the country, such as, Johannesburg, Pretoria, Cape Town, and Bloemfontein by national roads. It is also found that the city is about on an average of 800 km from some of the major cities in South Africa, i.e. Cape Town, Polokwane, Nelspruit and the town of Springbok. Apparently the city is the central point of the country from the road network point of view.

The CBD performs important urban functions of the city. It provides facilities for both commercial and administrative activities. Spatially, it is bounded by Quinn Street in the East, Cecil Sussman/Quinn Street in the North, Cecil Sussman/Bultfontein road in the west, and Lennox Street in the South, and is considered as the primary focused study area of the investigation. The arterial roads, which generally influence the traffic movement in the CBD area, are Long, Barkly, Bishop, Carter, Schnidtsdrif, Memorial and Transvaal Roads (Figure 1). As mentioned above these roads in an around the CBD area are under heavy pressure because of the combined movement of heavy vehicles in and out of the city and normal inter and intra city traffic resulting to inefficient traffic movement.

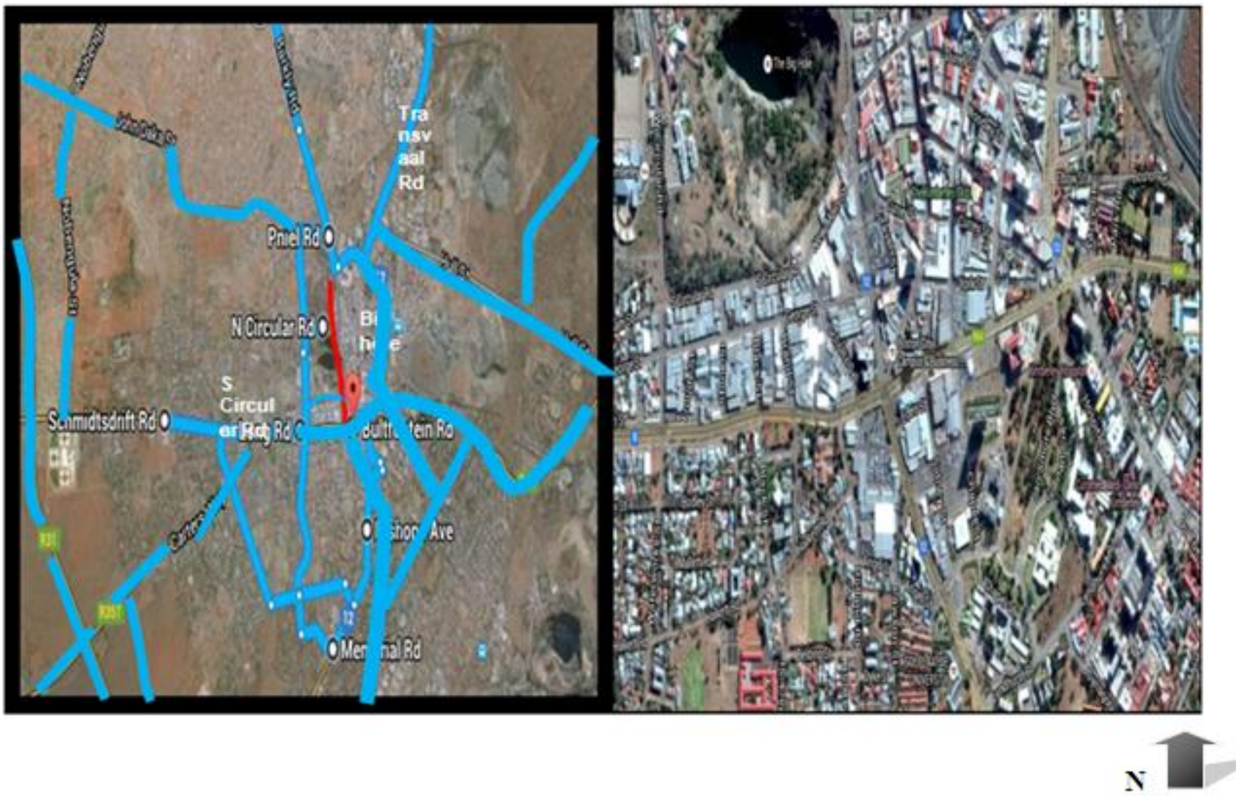


Fig. 1.
Road Network in the CBD Area of Kimberley City

4. Research Methodology

Since the investigation requires field data and road users' perception, a survey research method followed by quantitative analysis by use of statistical and empirical mathematical models suitable for analysing the traffic scenarios on the roads in and around the CBD area of city is observed to be most relevant (Kadiali, 2008). So, data were collected from primary and secondary sources. The primary data were collected from road user survey and traffic survey. The surveys were conducted by using established survey methodology applicable for transportation and traffic planning and design purposes. The collection of data from primary sources was essential because structured and up-to-date statistical data of important parameters with regard to traffic scenarios in the study area were not available. Moreover, the perception of road users and the opinion of stakeholders are essential for the development of strategies and policy interventions for alleviation of traffic congestion and efficient and smooth flow of traffic.

A number of relevant variables were taken into consideration for identification of suitable sites to conduct the surveys. Traffic surveys that included volume, speed, queue length at traffic junctions; travel time; delay time and speed changes of traffic were conducted at different locations on the important roads passing through and around the CBD area. The criteria used for selection of these roads include the importance of the road, its proximity and influence on the CBD and associated urban functions, volume of traffic, traffic flow pattern, speed of vehicles, congestion level and safety level. Based on these parameters, traffic surveys were conducted on the following roads: Long Street, Barkley Road, Bishop`s Road, Carter`s Road, Schmidtsdrift Road, Transvaal Road impacted by Pniel Road, Barkley section 2 impacting Transvaal Road, Main Street, Memorial Road, Du Toitspan Street, Lyndhurst Street, North Circular Street, South Circular Street and Cecil Sussman Street (refer Figure 1). Besides, road user perception and travel behaviour survey were conducted among 208 (N= 208) road users by using random sampling process at important nodes of the city.

The data collected were statistically analysed by the use of descriptive statistics, tabulation and significance tests. The determination of traffic congestion indicators such as traffic transmission index (Q index), LOS, travel time index (TTI), segment delay time (Ds), were done by applying the empirical models. Forecasting of traffic and simulated scenario analyses were then conducted with the aim to develop policy/ strategic interventions.

Using the values assigned by the respondents as obtained from the road user survey, a perception index (PI) of the road users was developed by employing a weighted average index method. The variables were grouped under four categories, namely land use and urban functions, urban pattern, road geometry and other urban development related parameters. The influence of each variable was assessed according to a scale of 0 to 1. Based on the perceptions and / or direct and indirect experience of respondents regarding transportation and traffic systems, urban movement challenges and traffic congestion scenarios, they were asked to assign a value in a scale of 0 to 1 to each variable which influences the occurrence of traffic congestion. The model used for the development of the perception index is presented below.

$$\text{Perception weighted average index} = (PI) = \frac{\sum Pi * Ni}{\sum Ni} \tag{1}$$

Where; Ni: number of respondents, PI: index values provided by the respondents in a scale of 0 to 1 as obtained from the road user survey.

5. Findings and Discussion

5.1. Perception index of factors causing congestion

Perception index (PI) was computed based on road users' perception on various factors that could cause congestion on the roads. A PI value of ≥0.70 is considered as highly influential, whereas a PI value between 0.5 and 0.7 (0.5<PI<7.0) is considered as moderately influential. Any PI value less than 0.5 (PI< 0.5) is taken as less influential in causing congestion. The various broad parameters considered for these analyses include physical road factors, spatial/ land use and urban function factors, traffic factors, behavioural factors, environmental and emergency factors.

Table 1 presents the perception indices of the various factors under each broad parameter. It is thus found that indices on road parking facilities (PI=0.76), and type of junctions (PI=0.74) are the major physical and road factors which significantly influence congestion on the roads in and around the CBD area of Kimberley. Unavailability of space near junctions (PI=0.68); availability of commercial functions (PI=0.54); and availability of traffic nodes such as bus stops, taxi stops and civic/administrative functions (PI=0.54) are the spatial variable that influence congestion. Similarly, traffic volume (PI=0.78) and type and composition of vehicles (PI=0.72) – particularly the plying of heavy vehicles (large trucks), traffic speed (PI=0.54) and traffic calming measures such as speed breakers (PI=0.52) – are perceived to be the major traffic related variables which significantly cause traffic congestion. Similarly, influence of alcohol and nausea on driver (PI=0.68); disrespect of traffic rules and regulations by road users (PI=0.62); unruly driver behaviour (PI=0.64); poor physical and mental condition of driver (PI=0.62); lack of knowledge of traffic rules (PI=0.56) under behavioural factors and occurrence of accidents (PI=0.66) under environmental and emergency factors which contribute largely the traffic congestion in the CBD area of the Kimberley city.

Variables such as lack of median facilities; unavailability of pedestrian crossing facilities; poor road conditions; lack of pavements/ footpaths; informal commercial activities; building offset; encroachment of roads; building size; pedestrian volume; traffic signs and pavement marking; stop signs; traffic rule enforcement such as speed traps, road blocks and unscheduled stops; and environmental factors such as heat, rain, storms and slippery roads; are perceived not to cause congestion on the roads of the study area.

Table 1
Perceptions of Public and Road Users Regarding the Parameters Influencing Traffic Congestion

Parameters	Index values	Rank	Parameters	Index values	Rank
Physical road factors			***Spatial/ Land use/ urban function factors***		
Capacity/Road width/ Lane width	0.55	5	Availability of commercial function	0.54	2
Number of lanes	0.58	3	Encroachment of roads	0.33	6
Footpaths/ pavements	0.35		Availability of civic/administrative functions	0.52	3
On-road parking facilities	0.76	1	Inadequate space available near the junctions	0.68	1
Median facilities	0.48	6	Building size	0.32	
Road condition	0.42	7	Building offset	0.38	5
Pedestrian crossing facilities	0.48	6	On-road informal commercial activities	0.47	4
Type of junctions	0.74	2	Availability of traffic nodes such as bus and taxi stops	0.54	2
Turning radius at junctions	0.56	4			
Traffic factors			***Behavioural factors***		
Traffic volume	0.78	1	Knowledge of traffic rules	0.56	4
Type and composition of vehicles	0.72	2	Respect of traffic rules and regulations	0.62	3
Traffic speed	0.54	3	Driver behaviour	0.64	2
Pedestrian volume	0.46	6	Driver's physical and mental condition	0.62	3
Signalling, pavement markings, signage control	0.44	7	Influence of alcohol and nausea	0.68	1
• Traffic signs and pavement marking	0.36	*9*	***Environmental and Emergency related factors***		
• Stop signs	0.41	8	Accidents	0.66	1
• Traffic calming measures such as speed breakers	0.52	4	Rain and storms	0.27	5
			Heat	0.28	3
• Traffic rule enforcement such as speed traps	0.48	5	Slippery roads	0.19	5
			Road blocks and unscheduled stops	0.44	2
Re-engineering measures for reduction of traffic congestion					
Availability of information through Information and Communication Technology (ICT)	0.43	10	Changing the traffic pattern	0.67	3
Segregation of heavy and light vehicles (Modal split)	0.73	2	Making one way streets	0.57	6
Diversion measures (Traffic assignment: choosing a different route)	0.76	1	Closure of roads (partial)	0.33	15
Use of public transportation systems	0.52	8	Segregation of vehicular and pedestrian traffic	0.36	14
Off-street parking provision	0.58	5	Improving the road infrastructure		
Removal of on-street parking system	0.56	7	• Improving junctions	0.66	4
Pedestrianisation of the whole CBD	0.32	16	• Increasing lane width	0.39	13
Pedestrian facilities in major areas	0.24	17	• Increasing number of lanes/road width	0.46	9
Improvement of signalling system	0.4	12	• Provision of pedestrian islands	0.43	10
Installing cameras/ videography	0.46	9	• Provision of footpaths/ pavements	0.42	11
Creation of traffic awareness and improving driver/user knowledge on traffic rules and regulations	0.56	7	Any other - please specify	-	

Source: Based on the statistical PI analysis from road user data collected, 2015

5.2. Level of congestion

The congestion analysis in the area was conducted by using empirical models such as segment delay, TTI, Q index and LOS particularly during peak hours. It is noted that the city experience two peak hours in the day such as (1) from 7.00-8.30 hours (in the morning) and (2) 16.00-17.30 hours (in the evening) and the major roads passing through the CBD area are found to be significantly congested during these periods. Table 2 presents the congestion levels on the roads of in and around the CBD based on the four mentioned analyses. According to the segment delay analysis, maximum delay occurs on Long Street followed by Transvaal Road impacted by Pniel. Moderate delay occurs on Bishop Street and Barkley section 2 impacting Transvaal Road and other roads do not experience much segment delay. The TTI analysis indicated that road sections close to the CBD such as Long Street, Transvaal impacted by Pniel Road, Barkley section 2 impacting Transvaal Road, and Schmidtsdrift Road are under severe pressure, followed by Bishop`s Road. The Q indices show that Long Street, Transvaal Road impacted by Pniel Road, Bishop`s Road and Barkley section 2 impacting Transvaal Road have relatively high congestion levels. Roads such as Schmidtsdrift Road, Cecil Sussman Road, Memorial Road and Lyndhurst Street are moderately congested. The LOS of various roads show that both Transvaal Road (influenced by Pniel Road) and Long Street are highly congested (LOS F); and Bishop`s Road could become a cause of concern (LOS C) in the current scenario. The LOS of various roads during peak hours show in the future scenario (in the projected year of 10 years from current) revealed that the level of congestion levels in Transvaal Road (influenced by Pniel Road) and Long Street will be further aggravated. The situation of Bishop`s Road will also become worse (LOS D). Carter`s Road, Barkley Street impacting Transvaal Road and Schmidtsdrift Road could also become cause of concern. All other roads are will be least congested. Thus, it is found that Maximum congestion occurs on Long Street and Transvaal Road, are experiencing critical congestion particularly during the peak hours of the day, and likely to be further aggravated in future whereas the scenario of Bishop`s Road is expected to become critical in future.

Table 2
Level of Congestion on Different Roads (Peak hours)

Roads	**Segment (Ds)**	**Travel Time Index (TTI)**	**Traffic Transmission index (Q index)**	**V_p/C Current scenario**	**LOS (Peak hours) Current**	**V_p/C Future scenario**	**LOS (Peak hours) Future scenario**	**Level of Congestion**
Long	92.06	2.5	266.67	1.24	F	1.48	F	HC
Barkley	6.66	1.66	600.00	0.21	A	0.25	A	LC
Bishop	34.71	2.00	227.27	0.74	C	0.88	D	MC
Carter	14.20	1.62	411.11	0.49	A	0.58	A	LC
Schmidtsdrift	27.97	2.22	337.50	0.49	A	0.58	A	MC
Barkley section 2 impacting Transvaal	30.81	2.22	300.00	0.54	A	0.64	B	MC
Memorial	10.96	1.76	377.78	0.31	A	0.37	A	LC
Transvaal influenced by Pniel	79.69	2.22	245.45	1.40	F	1.66	F	HC
Du Toitspan	7.01	1.62	493.33	0.24	A	0.29	A	LC
Main	2.54	1.50	533.33	0.11	A	0.13	A	LC
Lyndhurst	3.68	1.58	380.00	0.14	A	0.16	A	LC
North Circular	1.35	1.33	450.00	0.09	A	0.10	A	LC
Cecil Sussman	10.71	1.88	355.56	0.26	A	0.31	A	LC

5.3. Intervention measures to alleviate traffic congestion

According to the perceptions of the road users (Table 1) on the remedial solutions revealed that diversion of vehicles from congested roads (PI= 0.76), modal split (segregation of heavy vehicles from normal cars) (PI= 0.73) and changing traffic pattern (PI= 0.67) are the major re-engineering interventions which could alleviate traffic congestion in the study area. It is also perceived that provision of off-street parking (PI= 0.58), removal of on-street parking (PI=0.56) and one-way streets could assist in the reduction of congestion. Furthermore, under the improvement of road infrastructure, road users perceive that the junctions should be improved (PI= 0.66). Moreover they are of opinion that the creation of traffic awareness and improving driver/user knowledge on traffic rules and regulations (PI=0.56) and improvement of public transportation (PI=0.52) are essential challenges that need to be looked at. According to road users, measures such as availability of information through Information and Communication Technology (ICT), closure (partial) of certain road segments segregation of vehicular and pedestrian traffic, pedestrian facilities in major areas, pedestrianisation of the CBD area, improvement of the signalling system, and installation of cameras/ videography may not assist in reducing congestion as well as fully acceptable..

Moreover, significant tests were conducted to establish the relationship between the two important re-engineering policy intervention scenarios (1) adequate traffic assignment through traffic diversion from congested roads to relatively free roads and (2) segregation of vehicles (modal split) and level of traffic congestion (V/C) on the important congested roads in the CBD area. The tests were conducted by using t- test and p (one-tailed and two-tailed) values (significance test) for a confidence level of 95% ($\alpha \leq 0.05$). Table 3 presents the results of t-test and p vales. The table indicates that under the different policy interventions of traffic diversion and assignment on the one hand and modal split on the other hand, the p values (both one-tailed and two-tailed) are significantly low (<0.05) for $\alpha \leq 0.05$. It thus establishes that (a) segregation of traffic (modal split) will appreciably reduce traffic congestion in terms of improved LOS, less travel time and reduced delay on the roads of the CBD and (b) optimal traffic assignment (diversion to alternative roads) will significantly reduce traffic congestion in terms of improved LOS, less travel time and reduced delay on the roads of the CBD.

Table 3
Relationship Between Policy Interventions Scenarios and Congestion Level

Policy intervention scenarios for alleviation of congestion	T value	df	p*	p**
Traffic diversion and assignment: Normal hours - current scenario	7.007	27	0.00000008	0.00000016
Traffic assignment and percentage traffic diversion: Peak hours - current scenario	6.72	27	0.00000016	0.00000033
Combination of modal split and traffic assignment: Peak hours - current scenario	7.10	27	0.00000006	0.00000012

*Note: *One- tailed, **Two- tailed*

A comparative analysis based on simulated scenarios of different policy interventions suggests that normal hours do not need any policy interventions in the current situation. However, a minimum of 20.77% of traffic from Long Street and 28.80% from Transvaal Road should be diverted during the peak period. In addition about 15.11% of the traffic from Bishop Street, 12.73% from Barkley Road, 9.0% from Barkley section 2, 14.10% from Carter Road and 20.77% from Cecil Sussman road can be diverted. All the vehicles diverted can be assigned in proportions of 12.23%to Memorial Road, 20.77% to Du Toitspan Street, 20.77% to Lyndhurst Street, and 25.80% to Main Street. Similarly, during peak periods in the projected years (in ten years time- in the year 2026), a minimum diversion of 33.71% of the traffic from Long Street and 40.05% from Transvaal Road should be executed. About 17.79% of the traffic from Bishop Street may be diverted. Consequently, about 25.0% of the diverted traffic may be assigned to Memorial Road and Barkley Road impacted by Pniel Street and 28.43% may be equally assigned to Du Toitspan, Lyndhurst, and Main Street in order to reduce the traffic congestion and make proportionate distribution to reduce under utilization of in CBD area of the city. In future (the projected year), necessary provision should be made not to allow all the heavy vehicles to ply on Transvaal Road (Phakamile Mabija Road) and Long Street during peak hours and these vehicles may be assigned to roads such as Main Street, Du Toitspan and Lyndhurst Street.

6. Conclusion and further research

Traffic congestion is observed to be a challenge in the Kimberley City particularly in some of the roads in the CBD area, which needs interventions to alleviate the challenge. So this study was conducted to examine the levels of traffic congestion in both current and future scenarios and explore plausible re-engineering solutions to reduce the congestion level in the CBD area. The study was conducted by use of a survey research method and statistical tests and empirical. It is found that two of the roads Long Street and Transvaal Road are highly congested and are expected to worsen more in future. Another road Bishop's road is expected to become critical in near future. Since all other roads have lower level of LOS, they seem to be under utilised. In this regards traffic assignment - diversion vehicles in appropriate proportions (such as a minimum of 20.77% in current and 33.71% in future from Long Street and 28.80% in current and 40.05% in future from Transvaal Road) and assigning them to least congested roads such as Memorial Road, Barkley Road impacted by Pniel Street, Du Toitspan, Lyndhurst, and Main would reduce traffic congestion appreciably. Besides it is necessary not to allow all the heavy vehicles to ply on Transvaal Road and Long Street during peak hours in future and these vehicles may be assigned to roads such as Main Street, Du Toitspan and Lyndhurst Street. However, the study was limited to analysis of traffic congestion and re-engineering solutions and the preparation of detailed traffic management plan was kept out of the scope of this research, which the authors are keen to take as a part of their further research plan.

References

Alterkawi, M.M. 2006. A computer simulation analysis for optimizing bus stops spacing: the case of Riyadh, Saudi Arabia, *Habitat International*, 30(3): 500-508.

Banjo, G. A. 1984. Towards a New Framework for Urban Transport Planning in Third World Cities. In *Proceedings of the Australian Road Research Board Conference*, 12(1).

Bass, P. 2008. Traffic Literature Review: Congestion and Quality of Intersections, Hamline Midway Coalition. Available from Internet: <www.cura.umn.edu/search/index.php>.

Chakwizira, J. 2007. The question of road traffic congestion and decongestion in the greater Johannesburg area: some perspective. In *Proceedings of the 26th Southern African Transport Conference (SATC 2007).*

Ceylan, H.; Bell, M.G.H. 2004. Traffic signal timing optimization based on genetic algorithm approach, including drivers' routing, *Transportation Research Part B*, 38(4): 329-342.

Chen, X.; Yu, L.; Zhang, Y.; Guo, J. 2009. Analysing urban bus service reliability at the stop, route, and network levels, *Transportation Research Part A*, 43(8): 722-734.

Cordeau, J.; Laporte, G.; Savelsbergh Martin W.P.; Vigo, D. 2007. Vehicle Routing Chapter 6 C. Barnhart and G. Laporte (Eds.), Handbook in OR & MS, Vol. 14, DOI: 10.1016/S0927-0507(06)14006-2.

Das, D.; Keetse, M. 2015. Assessment of Traffic Congestion in the Central areas (CBD) of South African Cities- A Case Study of Kimberley City. In *Proceedings of the 34th Southern African Transport Conference (SATC 2015)*, 836-850.

Department of transportation, U.S. 2005. Traffic congestion and reliability: Trends and advanced strategies for congestion mitigation, Office of Operations, Texas Transportation Institute, Federal Highway Administration. U.S.A.

Department for Transport 2000. Tackling Congestion and pollution: the Government's first report. Available from Internet: <http://www.dft.gov.uk>.

Department for Transport 2000b. A measure of Road Traffic congestion in England. Available from Internet: <http://www.dft.gov.uk>.

Dijker, T.; Piet, H.L.; Bovy, R.; Vermijs, G.M.M. 1998. Car following under non-congested and Congested conditions, *Transportation Research Record*, 1644: 20-28.

Dodgson, J.; Young, J.; Van der Veer J. 2002. Paying for Road Use, Technical 61 Report, A report to the Commission for Integrated Transport, *National Economic Research Associates (NERA*), London, February. Available from Internet: <http://www.cfit.gov.uk/docs/2002/pfru/research/pdf/pfru-tech.pdf>.

European Conference of Ministers of Transport, (ECMT) 1999. Report of the Hundred and Tenth Round Table on Transport Economics held in Paris on 12 -13” March 1998 on The following topic: Traffic Congestion in Europe, Paris: Economic Research Centre, European Conference of Ministers of Transport.

Furth, P.G.; Muller, T.H.J. 2009. Optimality conditions for public transport schedules with time point holding, *Public Transport: Planning and Operations*, 1(2): 87-102.

Gao, Z.Y.; Song, Y.F. 2002. A reserve capacity model of optimal signal control with user-equilibrium route choice, *Transportation Research Part B*, 36(4): 313-323.

Gifford, J. L. 2005. Congestion and its Discontents, in Access to Destinations, ed. D.M. Levinson and K.J. Krizek, 39-62, Elsevier Ltd, Amsterdam, Netherlands.

Graham, D.J.; Glaister, S. 2004. Road traffic demand elasticity estimates - a review, *Transport Reviews*, 24(3): 261-274.

Goodwin, P.B. 2004. The Economic Costs of Road Traffic Congestion. Discussion paper. Rail Freight Group, Transport Studies Unit, University College London. Available from Internet: <http://eprints.ucl.ac.uk/archive/00001259/>.

Grant-Muller, S.; Van Vuren, T.; Meekhums, R.; Poole, A.; Bhatti, A.; Gawthorp, S.; Chen, H.; Cavendish-Tribe, A. 2005. Assessment Methodology report, Project deliverable- Report 203754_MM_003.

Grant-Muller, S.; Laird, J. 2006. Costs of congestion: literature based Review of methodologies and analytical Approaches, Scottish Executive Social Research Institute for Transport Studies, University of Leeds. Available from Internet: <www.scotland.gov.uk/socialresearch>.

Hardjono, B. 2011. A review of existing traffic jam reduction and avoidance technologies, *Internetworking Indonesia journal*, 3(1): 19-24.

HCM 2000. *Highway Capacity Manual*, National Research Council, Washington D.C., U.S.A.

Highways Agency, Scottish Office development department, The Welsh Office, The department of the Environment for Northern Ireland 1997. Design manual for Roads and Bridges, Traffic Flow Ranges for Use in the Assessment of New Rural Roads. DMRB, Vol 5, Section1, Part 3. Available from Internet: <http://www.highways.gov.uk/>.

Lascano Kezic, E.M.; Durango-Cohen, P. L. 2012. The transportation systems of Buenos Aires, Chicago and Sao Paulo: City centers, infrastructure and policy analysis, *Transportation Research Part A*, 46(1): 102-122.

Levinson, H.S.; Lomax, T.J.; Turner, S.; 1997. Traffic Congestion - Past - Present- Future. In: Rahim, F. (Ray) Benekohal (ed.), Traffic Congestion and Traffic Safety. In *Proceedings of the 21st Century: Challenges, Innovations, and Opportunities*.

Link, H.; Dodgson, J.S.; Maibach, M.; Herry, M. 1999. *The Costs of Road Infrastructure and Congestion in Europe*, Physica-Verlag , Heidelberg, Germany.

Lomax, T.J. 1990. Estimating transportation corridor mobility, *Transportation Research Record: Journal of the Transportation Research Board*, 1280: 82-91.

Lomax, S.T.T.; Turner, S.; Shunk, G.; Levinson, H.S.; Pra, R.H.; Bay, P.N.; Douglas, G.B. 1997. *Quantifying congestion, Volume 1, NCHRP Final Report 398*, Transportation Research Board, Washington, D.C., U.S.A.

Meyer, M. 2003. *Synthesis. Presentation at Traffic Congestion: Issues and Options*, University of California at Los Angeles, Los Angeles, U.S.A.

Noland, R.B.; Polak, J.W. 2002. Travel time variability: a review of theoretical and empirical issues, *Transport Reviews*, 22(1): 39-54.

Salicru, M.; Fleurent, C.; Armengol, J.M. 2011. Timetable-based operation in urban transport: Run-time optimisation and improvements in the operating process, *Transportation Research Part A*, 45(8): 721-740.

Santos, L.; Coutinho-Rodrigues, J.; Current, J.R. 2008. Implementing a multi-vehicle multi-route spatial decision support system for efficient trash collection in Portugal, *Transportation Research Part A*, 42(6): 922-934.

Stateside Planning Scenario Synthesis 2005. *Transportation congestion measurement and management-research report KTC-05-32/SPR303-05-iF*, Kentucky Transportation Centre, Kentucky, U.S.A.

Stevanovic, A.; Stevanovic, J.; Kergaye, C. 2013. Optimization of traffic signal timings based on surrogate measures of safety, *Transportation Research Part C*, 32: 159-178.
Surface Transportation Policy Project (STTP) 2001. Easing the Burden: A Companion Analysis of the Texas Transportation Congestion Study. Available from Internet: <http://transact.org/>.
Talukdar, M.H 2013. Framework for Traffic Congestion Management, *Economia, Seria Management*, 16(1): 54-64.
Taylor, B. 2002. Rethinking Traffic Congestion, *Access*, 21: 8-16.
Watling, D.; Milne, D.; Clark, S. 2012. Network impacts of a road capacity reduction: Empirical analysis and model predictions, *Transportation Research Part A*, 46(1): 167-189.
Yang, H.; Bell, M.G.H 1998. Models and algorithms for road network design: a review and some new developments, *Transportation Review*, 18(3): 257-278.
Yin, Y.; Lam, W.H.K. Miller, M.A 2004. A simulation-based reliability assessment approach for congested transit network, *Journal of Advanced Transportation*, 38(1): 27-44.
Zanjirani Farahani, R.; Miandoabchi, E.Z.; Szeto, W.Y.; Rashidi, H. 2013. A review of urban transportation network design problems, *European Journal of Operation Research*, 229(2): 281-302.

PASSENGER HANDLING FUNCTIONS IN AUTONOMOUS PUBLIC TRANSPORTATION

Dávid Földes[1], Csaba Csiszár[2]
[1,2] Budapest University of Technology and Economics (BME), Faculty of Transportation Engineering and Vehicle Engineering (KJK), Department of Transport Technology and Economics (KUKG) Budapest, Hungary

Abstract: Emerging infocommunication and vehicle technologies (e.g. autonomous vehicle) facilitate evolvement of autonomous public transportation in urban areas. It involves launching new service concepts (e.g. telematics-based shared demand responsive transportation), transformation of existing modes and automatization of passenger handling functions. However, there are debates about which processes how to be automatized. The aim is to replace human personnel by machines so as to improve service quality and decrease expenditures. The research questions were, how the functions are to be automatized and what the consequences are on both the machine and the human side. All the passenger handling functions, the existing and altering ones as well as the new functions have been investigated in process and system oriented approach. We have considered the most relevant technological novelties and their application opportunities, and then the required abilities (skills) of travelers. We have revealed correspondences among functions and human abilities. The shifting of intensities of human abilities (cognitive capability) have been estimated. Personnel groups with altering or new functions have been introduced and the functions of the replaced driver have been assigned to the groups or the machine components. Both the gains and the occurrent drawbacks have been assessed. The presented results appoint the research and innovation trends and directly facilitate the developments (e.g. design of smart devices and services as human-machine interface).

Keywords: passenger handling, automatization, autonomization, human abilities, cognitive capability.

1. Introduction

Mobility is to be considered as a complex service, not only providing transportation, infrastructure, etc., where humans are the key elements. Investigation of human components in the passenger transportation system is one of the most challenging tasks as perceptions are strongly heterogeneous, dynamic (evolves in time as an individual goes through different life stages), context dependent and also influenced by the environment. Several smart city and autonomous vehicle projects have already focused on either the city or the vehicle itself but not on the citizens or passengers, who are the end users of the services (Pribyl and Horak, 2015). On the other hand, the role of personnel (drivers, staff) is to be reduced and replaced by machines, where it is required or possible. As these two types of human components are strongly interrelated, introduction of autonomous vehicle (AV) based services requires and implies significant transformation of passenger transportation. The research questions were:

1. which functions and how to be automatized (opportunities)?
2. how does the future traveler's sensations and cogitation change?
3. what kind of modifications are possible in role of personnel?

The automatization in transportation has retrospected for decades. The first autopilot system in flight was introduced in 1912, the first automatic train operation started at 1967 in London. Air transportation has been always foregoer, as the functions and services are especially advanced and automatized (e.g. check-in, baggage sorting system). Nowadays, the manufacturers are developing autonomous road vehicles, which have been already introduced also in everyday operation. Generally, five stages are distinguished in development of AVs which has been identified how the driving tasks are transferred from human to machine. The technological development enables widespread automatization, however several aspects and issues are to be tackled (e.g. safety-security issues, acceptance of the new technologies). The major social impacts of AVs have been described: safer roads (less accidents), travel time reduction, more personalized services, improvement of energy efficiency and parking benefits (Fagnant and Kockelman, 2015).
The future urban mobility system is envisaged by scientific literature as follows: majority of the vehicles are electric, motorized transportation modes are served by autonomous vehicles (Godoy et al., 2015), most of the transportation modes merge into one 'new' integrated, telematics-based, shared mode, ownership of individual motorized vehicles is decreasing, the emphasis is taken on the service instead of the vehicle and sharp boundaries between infrastructure elements are also declining (e.g. AVs drive in buildings arriving as close to the destination as possible). Model about operation of fleet of Shared Autonomous Vehicles (SAV) has been elaborated by Fagnant and Kockelman (2014). According to the model each SAV travels to its final destination only if at least one passenger is carried on the board. The vehicles do not serve defined stop points between origin and destination. The concept of 'Mobility as a Service' (MaaS), which offers convenient door-to-door transportation without the need to own a private vehicle, covers tariff and payment integration, ICT integration and introduction of various mobility packages. An evaluation index about the level of mobility integration has been elaborated in order to compare MaaS systems (Kamargianni et al., 2016).
The future urban transportation modes have been revealed and summarized by Földes and Csiszár (2016). The individual cars are used for the most flexible travel purposes. The other modes (existing conventional public transportation services, demand responsive public transportation, car-sharing, taxi, chauffeur service, car-pooling, ride-

[1] Corresponding author: foldes.david@mail.bme.hu

sourcing) are merging into the new mode (Telematics-based Shared Demand Responsive Transportation - TS-DRT) and the ride-sharing gains more and more importance. A simulation model has been developed by Winter et al (2016) which determines the minimal and optimal fleet size with minimizing the total operational and travel costs for operating a demand responsive, autonomous shuttle service in a campus. The introduction steps of AVs and their effects have been investigated by Davidson and Spinoulas (2015). They found that the increasing share of AVs in the mixed traffic (AVs and manual cars on the road at the same time) causes worse traffic flow parameters at an early stage (Tettamanti et al., 2015), but after achieving homogeneous AV traffic, the parameters are getting much better (Li et al., 2015). According to their vision, share of public transportation and cycling/walking will slightly decrease as a consequence of taking over passengers by new modes based on AVs. The autonomous transportation requires more intensive use of ICT tools and services by passengers (trip planner, electronic information, ticketing, etc.). However, the citizens are different, their requirements and expectations are rather diverse. Bak and Borkowsky (2015) found that users in different regions with very various characteristics (as e.g. wealth, GDP, cultural background) can be represented by surprisingly similar attitudes towards ICTs (e.g. purpose of using an application).
The remainder of the paper is structured as follows. Definition of basic terms are provided in Section 2. The method of investigation of passenger handling functions forms the body of Section 3, where the functions and the required human abilities have been also revealed. Section 4 presents the results, namely the transformed functions and the altered human behavior in the future transportation system. Results are discussed in Section 5. Finally, in Section 6 the conclusions are drawn and the future research directions are summarized.

2. Definition basic terms

We have defined the basic terms:

- **Automated functions** are operated by machine which follows very clearly described, step by step rules. The rules have been programmed into them one by one.
- **Autonomous functions** are operated by machine which is able to make individual decisions using cognitive capabilities and learning abilities. Not all situations have to be mapped in advance, the new situations are perceived, understood and properly managed.
- **Autonomous public transportation**: a system using autonomous technology by vehicle, infrastructure and traveler in order to improve operation and enhance service quality. Most of the components are equipped by sensors, cameras, etc. and communication channels in order to realize V2X cooperation. Technologies either imitate human procedures (e.g. sensing, learning) or realize human-independent new procedures (e.g. localization). The efficiency of operation can be refined and perfected by the new information that is collected by new sensing technologies and was not available before by human sensing. The personnel (e.g. dispatcher, driver, inspector) is eliminated and replaced by machine components in several cases. The mobility service consists of both services on fixed, high capacity arterial routes (mostly based on railways) with regular schedule and flexible, demand responsive services, which may have either feeder or point-to-point role. The latter one is efficient where the demands are low and/or dispersed (International Transport Forum, 2015). The vehicles are in public property. The passenger handling functions are mostly performed without direct human interventions.
- **Passenger handling functions and services**: the functions that are connected to passengers' basic movement and information management before, during and after travel in case of both normal and emergency situations. The functions are realized by either automated (e.g. ticket validation with electronic devices) or autonomous (e.g. providing value added personalized information by recognizing the traveler and learning his/her habits) services. In the first case pre-programmed operation is performed; whereas in the second case the system is able to react to the actual situation using its cognitive capability. One service may cover one or more functions.

3. Method of investigation of passenger handling functions

In order to determine the development potential and effects of automatization on both the machine and the human side, the functions and the human abilities have been investigated in process and system oriented approach. The elaborated method produces quantitative results to compare and prioritize the future developments (Fig. 1.). The main result is the automatization (Computerization) potential value (C_i) on machine side and the Aggregated Ability alteration value (AA_j) on human side. (Computerization word is used as a synonym for automatization in order to create distinct acronyms). They are calculated as difference of future and current indicators and being highlighted by grey colored boxes. C_i expresses the relevance of automatization of the function, where i is the index of function. AA_j expresses how the alteration of the functions influences passengers' required abilities, where j is the index of ability. The higher values indicate higher development potential and more significant alteration. Using the method other important values may be calculated as results of comparison of indicators: automatization level alteration (l_i), human ability indicator alteration (A_{ij}) in the given function, and human ability intensity alteration (a_{ij}) in the given function. The revealed functions are almost the same currently and in the future, however their properties alter (e.g. required human and machine actions). The identified passenger handling functions have been categorized into function groups (Table 1).

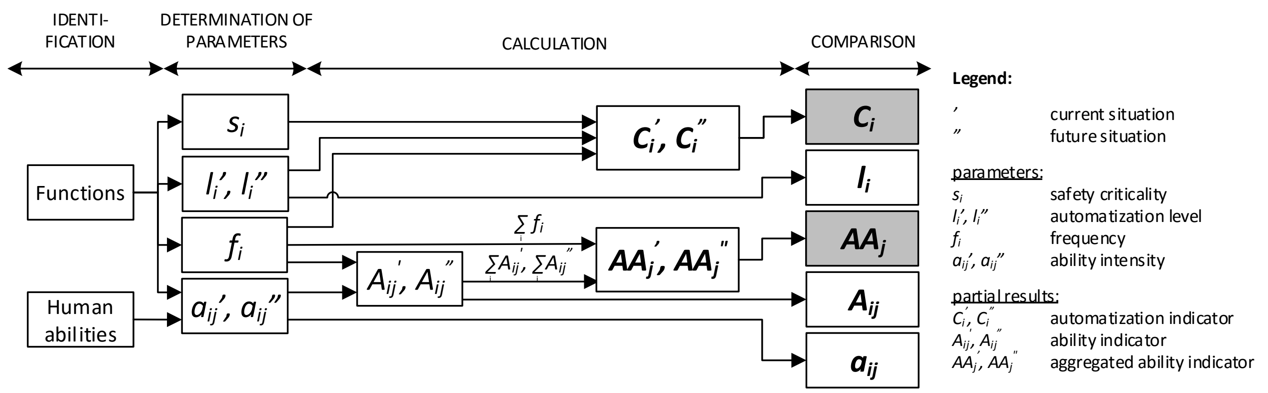


Fig. 1.
Flow-chart of method

Table 1
Functions

function groups nr.	function groups name	functions sign	functions name
1	infotainment	F_{11}	information provision about general conditions and supplementary services
		F_{12}	information provision about current situation
		F_{13}	personalized journey planning and guiding/ navigation
		F_{14}	activity chain planning
		F_{15}	information provision by installed devices (in the stop/station)
		F_{16}	on board information provision by on board devices
		F_{17}	on board complaining/information request
		F_{18}	communication between vehicle-passenger
		F_{19}	entertainment
2	management of entitlement	F_{21}	seat reservation
		F_{22}	payment
		F_{23}	ticketing
		F_{24}	check-in (ticket validation)
		F_{25}	control of entitlement (ticket inspection)

function groups nr.	function groups name	functions sign	functions name
3	safety	F_{31}	avoiding accidents between vehicle and passengers
		F_{32}	handling boarding process (warning, open/ close door)
		F_{33}	handling passengers in diseased conditions
		F_{34}	handling fire cases
		F_{35}	handling traffic collisions - evacuation
		F_{36}	handling vehicle technical failures (broke down)
		F_{37}	handling equipment technical failures
4	security	F_{41}	property protection (individual/common)
		F_{42}	life protection
		F_{43}	emergency call
		F_{44}	safeguard against terrorism
5	management of passenger room/ cabin conditions	F_{51}	management of comfort (e.g. heating, lighting, cleaning)
6	management of feedbacks	F_{61}	complaining
		F_{62}	crowd sourcing
		F_{63}	lost and found
		F_{64}	data collection from/about passenger
		F_{65}	data collection from/about vehicle/infrastructure

3.1 Calculation of indicators on machine side (functions)

Determination of parameters:

- safety criticality (s_i): how much the function should be reliable in safety critical circumstances/situations (Table 2). Same safety criticalities are assumed also in the future.

Table 2
s_i values

value	safety criticality	description
1	not	not safety critical
2	medium	slightly jeopardize human safety/life
3	high	sorely jeopardize human safety/life

- automatization level (l_i): in what degree the function can be automatized, in other words how it is possible to replace the human operations or presence by machine (Table 3). It is a general parameter which does not reflect particular aspects of operators/users. The current (l_i') and the future (l_i'') parameters have been assessed.
- frequency (f_i): average frequency of the function during travels (Table 4). Same frequencies are assumed also in the future.

Calculation of C_i' and C_i'' – Automatization indicators (1): The strong effect of safety criticality is expressed by power function. Calculation method of indicator is similar in both the current (C_i') and future (C_i'') situations. $C_i \in [0..625]$ in case of the introduced values.

$$C_i' = f_i \cdot l_i'^{s_i} \tag{1}$$

Table 3
l_i values

value	automatization level	description
1	low	no machines
2	rather low	slight machine support
3	medium	significant machine support
4	rather high	humans are needed only in safety critical situations
5	high	humans are unnecessary (only supervisors for remote control)

Table 4
f_i values

value	frequency	description
1	very rarely	in case of safety critical situations
2	infrequently	during some travels
3	occasionally	during many travels
4	frequently	during each travel a few times
5	very frequently	during each travel several times

Calculation of differences of indicators (2) or parameters (3) regarding future and current situations (Table 5). Difference between l_i values makes independent analysis possible. C_i is a complex indicator, because frequency and safety criticality are also included. Difference values are to be used for specification of software and hardware requirements during development of the certain functions.

Table 5
Calculation of differences on machine side (functions)

sign	calculation	description
C_i	$C_i^{"} - C_i' = f_i \cdot l_i^{"s_i} - f_i \cdot l_i'^{s_i}$ (2)	relevance of development
l_i	$l_i^{"} - l_i'$ (3)	required or foreseeable development

3.2 Calculation of indicators on human side (passenger)

During development of functions the alterations of required human abilities and cognition are to be investigated and considered as they significantly influence the perceived quality of service. The elaborated analysis method provides results mapping this alteration in a quantitative way. The most relevant human abilities have been identified.

1. eyesight,
2. hearing,
3. speaking,
4. touching,
5. typing,
6. reading,
7. operations by hand,
8. vibration sensing,
9. cognitive capability.

Vibration sensing is an important ability to sense vibration of a device placed in pocket or hand. Cognitive capability is defined as recognition and persistent learning capability. Travelers are able to create new, reliable, value-added information using previous experience, existing knowledge and ambiguous, incomplete secondary information sources. Cognitive capability is rather complex, it includes sensing and processing methods too.
The required abilities are altering as consequence of automatization. We have revealed the ability intensities (as parameters) for the current (a_{ij}') and future (a_{ij}'') situations in case of each function (where j is the index of the ability). Intensity expresses how long the ability is required during the function (Table 6). The low intensity is more convenient for the passenger. AA_j is created by consideration of frequencies and then aggregation of multiplied ability intensities.

Table 6
a_{ij} values

value	ability intensity	description
0	never	unrequired ability
1	rather low	for only a moment
2	low	for a short time
3	medium	cca. half of the time
4	rather high	all time with small pauses (almost continuously)
5	high	all time (continuously)

Calculation of A_{ij}' and A_{ij}'' - Ability indicators (4): frequency influences ability demands during travels, therefore it is considered as a multiplier. Calculation method of indicator is similar in both the current (A_{ij}') and future (A_{ij}'') situations. $A_{ij} \in [0..25]$ in case of the introduced values.

$$A'_{ij} = f_i \cdot a'_{ij} \quad (4)$$

Calculation of AA_j' and AA_j'' - Aggregated Ability indicators (5): as the same ability is required in case of several functions, the demand of this ability can be calculated as a sum of Ability indicators by functions (i), which is divided by the sum of frequencies of all functions. The indicators are calculated for both the current (AA_j') and future (AA_j'') situations. $AA_j \in [0..5]$ in case of the introduced values. The highest the AA_j value is, the more required the ability is.

$$AA'_J = \frac{\sum_i A'_{ij}}{\sum_i f_i} \quad (5)$$

The alteration can be represented by the differences of indicators (6), (7) and parameters (8) regarding future and current situations (Table 7). If the values of differences are negative, the required ability is less than currently, which is advantageous for the traveler.

Table 7
Calculation of differences on human side

sign	calculation		description
AA_j	$AA_j^{"} - AA_j'$	(6)	indicates human sensing and cognitive effort alteration in aggregated way (regarding all functions); it is useful for training and preparation of traveler's senses to autonomous processes
A_{ij}	$A_{ij}^{"} - A_{ij}'$	(7)	indicates what ability how alters at the given function considering all the travels; it is useful for specification of software and hardware requirements during development
a_{ij}	$a_{ij}^{"} - a_{ij}'$	(8)	indicates what ability how alters at the given function; it is useful for specification of software and hardware requirements during development

3.3 Analysis of tasks of personnel

As drivers have passenger handling functions in many cases, their replacement by machine significantly modifies performance of the functions. Therefore, the tasks of personnel have been analyzed and the current driver functions have been identified and assigned to the future personnel groups or the new machine components.

4. Results

The presented results have been calculated by the elaborated method. The used parameters have been determined by assumptions or literature review and were applied for demonstration purposes. More precise determination of the parameters requires further researches (e.g. questionnaire surveys, analysis of human behavior).

4.1 Assessment of functions

The most important properties of functions are summarized in Table 8. Functions with high automatization level alteration $(l_i \geq 2)$ are marked with red numbers. Functions with significant automatization potential $(C_i \geq 100)$ are presented with grey background and bold numbers. They are safety critical and having high automatization level alteration. If both l_i and C_i are high, development requires special attention, as in the case of F_{18}: communication between vehicle-passenger, F_{24}: check-in (ticket validation), F_{31}: avoiding accidents between vehicle and passengers and F_{34}: handling fire cases.

Table 8
Properties of functions

	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	F_{18}	F_{19}	F_{21}	F_{22}	F_{23}	F_{24}	F_{25}	F_{31}	F_{32}	F_{33}	F_{34}	F_{35}	F_{36}	F_{37}	F_{41}	F_{42}	F_{43}	F_{44}	F_{51}	F_{61}	F_{62}	F_{63}	F_{64}	F_{65}
f_i	4	5	4	4	5	5	2	5	4	4	4	4	5	3	5	5	2	1	1	1	2	5	5	2	1	5	2	5	2	5	5
l_i'	3	3	3	3	3	3	1	1	3	3	2	2	2	1	3	4	1	1	1	1	2	2	2	2	2	2	1	4	1	4	4
l_i"	4	5	4	4	5	5	3	5	4	5	4	4	5	3	5	5	4	4	4	3	3	4	4	3	3	5	3	5	3	5	5
s_i	1	1	1	1	1	1	1	3	1	2	3	3	3	2	3	3	3	3	3	3	1	2	3	3	3	2	1	1	1	2	3
C_i'	12	15	12	12	15	15	2	5	12	36	32	32	40	3	135	320	2	2	1	1	4	20	40	16	8	20	2	20	2	80	80
C_i"	16	25	16	16	25	25	6	625	16	100	256	256	625	27	625	625	128	128	128	27	6	80	320	54	27	125	6	25	6	125	125
l_i	*1*	*2*	*1*	*1*	*2*	*2*	*2*	*4*	*1*	*2*	*2*	*2*	*3*	*2*	*2*	*1*	*1*	*3*	*1*	*2*	*1*	*2*	*2*	*1*	*1*	*3*	*2*	*1*	*2*	*1*	*1*
C_i	*4*	*10*	*4*	*4*	*10*	*10*	*4*	***620***	*4*	*64*	***224***	***224***	***585***	*24*	***490***	***305***	***126***	***126***	***126***	*26*	*2*	*60*	***280***	*38*	*19*	***105***	*4*	*5*	*4*	*45*	*45*

Legend: *high automatization level alteration*, ***significant automatization potential***

4.2. Assessment of human abilities

The role of several abilities is changing as consequence of automatization. Table 9 presents an excerption of the alteration of the required human abilities. The higher the value of cells is, the more the ability is required. Fig. 2. represents the required human abilities (*j = 1-8*) currently and in the future. As cognitive capability (*j*=9) is much more complex than sensing by organs, cognitive capability is not illustrated in the figure. The Aggregated Ability alteration values (AA_j) is used to illustrate the shifting.

Table 9
Required human abilities - excerption

	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	F_{18}	F_{19}	F_{21}	F_{22}	F_{23}	F_{24}	F_{25}	F_{31}	F_{32}	F_{33}	F_{34}	F_{35}	F_{36}	F_{37}	F_{41}	F_{42}	F_{43}	F_{44}	F_{51}	F_{61}	F_{62}	F_{63}	F_{64}	F_{65}	AA_j', AA_j"	AA_j
$a'_{1,i}$	4	5	4	3	4	4	1	2	3	3	3	3	4	4	3	4		5	5	5	3			2			2	1	3				
$a^{"}_{1,i}$	4	4	3	0	3	3	1	5	4	3	3	2	2	2	5	4		5	5	5	5			2			2	1	3				
$A'_{1,i}$	***16***	***25***	***16***	***12***	***20***	***20***	***2***	***10***	***12***	***12***	***12***	***12***	***20***	***12***	***15***	***20***		***5***	***5***	***5***	***6***			***4***			***4***	***5***	***6***			***2.46***	***-0.16***
$A^{"}_{1,i}$	***16***	***20***	***12***	***0***	***15***	***15***	***2***	***25***	***16***	***12***	***12***	***8***	***10***	***6***	***25***	***20***		***5***	***5***	***5***	***10***			***4***			***4***	***5***	***6***			***2.30***	
...	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
$a'_{9,i}$	3	3	4	5	3	3	1	2	2	3	2	3	4	3	5	3	2	3	3	3	2			4		2	3	3	3	2			
$a^{"}_{9,i}$	2	2	3	3	3	3	4	5	4	2	3	2	2	2	4	2	3	4	4	4	3			3		1	4	2	4	1			
$A'_{9,i}$	***12***	***15***	***16***	***20***	***15***	***15***	***2***	***10***	***8***	***12***	***8***	***12***	***20***	***9***	***25***	***15***	***4***	***3***	***3***	***3***	***4***			***8***		***10***	***6***	***15***	***6***	***10***		***2.55***	***-0,22***
$A^{"}_{9,i}$	***8***	***10***	***12***	***12***	***15***	***15***	***8***	***25***	***16***	***8***	***12***	***8***	***10***	***6***	***20***	***10***	***6***	***4***	***4***	***4***	***6***			***6***		***5***	***8***	***10***	***8***	***5***		***2.33***	

Legend: not relevant

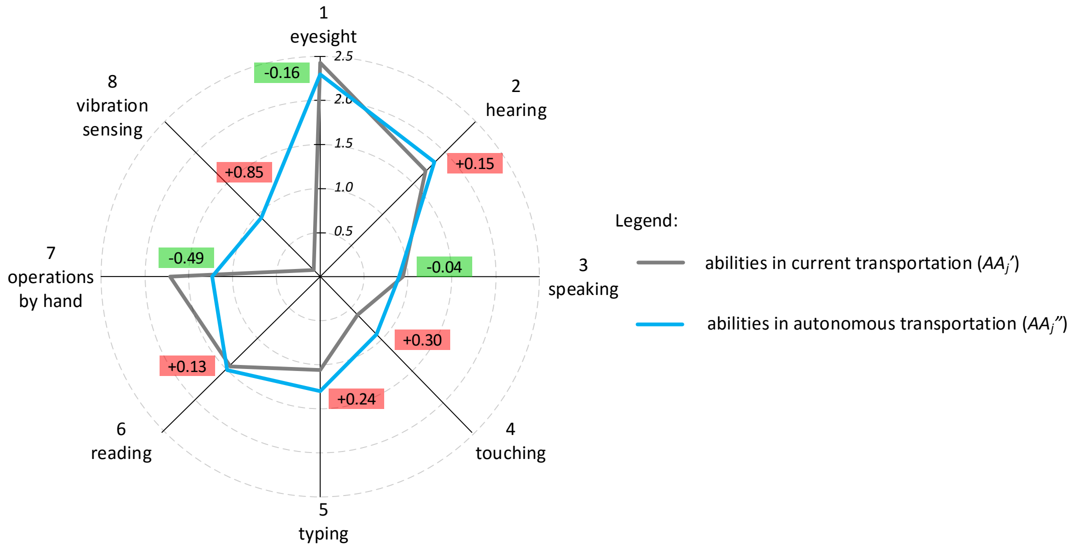


Fig. 2.
Required human abilities (AA_j', AA_j") and their alteration (AA_j)

4.3. Alteration in personnel tasks

The driver functions have been assigned to the different groups (types) of personnel and machines (installed in vehicle or station). This alteration in personnel tasks is represented by 'X' in cells of Table 10. These groups of personnel already nowadays perform several functions, however, their actions are altering as a consequence of modification of function properties and taking over driver functions.

Table 10
Reallocation of driver tasks among personnel groups

whom	F_{12}	F_{17}	F_{18}	F_{23}	F_{24}	F_{25}	F_{31}	F_{32}	F_{33}	F_{34}	F_{35}	F_{36}	F_{41}	F_{42}	F_{43}	F_{51}
machine	*X*		*X*	*X*	*X*	*X*		*X*								*X*
dispatcher	X						X		X	X	X	X			X	
supervisor		X							X	X	X	X				
customer service		X														
security team													X	X	X	
rescue team									X	X	X	X			X	

5. Discussion

The analyses pointed out the most relevant development potentials of functions. The first research question, which functions and how to be automatized, is to be answered by results of (2), (3), (7), (8) equations. (2) and (3) assesses the technological opportunities, whereas (7) and (8) provides the required human abilities. The second research question, how the future traveler's sensations and cogitation changes, is to be answered generally by results of (6) and in details by (7) and (8). The third research question, what kind of modifications are possible in role of personnel, is answered by results of Table 10. All the results are interrelated. The most relevant properties of future functions are described considering the results, then the general alteration of human abilities and tasks of future personnel are discussed. Not only the results presented in Table 9, but alteration of all relevant human abilities are discussed in this section too.
Information provision (F_{11}, F_{12}) becomes more location based, personalized, however, the automatization level does not change significantly /$l_{11}=1$/. The location has an impact on e.g. traffic, weather, business ads, coupons, free parking lots, etc. (Rao and Giuli, 2011). The speaking as an ability becomes more important only in case of these functions as consequence of voice-based communication /$a_{3,11}=2$, $a_{3,12}=1$/ and it replaces typing /$a_{3,11}=a_{3,12}=-1$/. Journey planning (F_{13}) and activity chain planning (F_{14}) play more important role as future mobility becomes more pre-planned and personalized (Esztergár-Kiss and Csiszár, 2016). Setting personal characteristics or route expectations requires more time in the first phase, however, later on less time is enough due to cognitive and persistent learning capability of the journey planners. Accordingly, less user cognitive capability is needed /$a_{9,13}=-1$, $a_{9,1}$ $=-2$/. Multimodality between modes or region can be achieved by integration of multiple journey planners (Nykl et al., 2015). The installed information provision (F_{15}) devices provide more information in more automatic way /$l_{15}=2$/, not only about transportation related news, but e.g. about weather, touristic information too. Smart stops are installed as service hubs where travelers receive several information in automatic way. Information about current position, route, next stop, or other location based services are provided via on board devices (F_{16}). The travelers cannot complain to the driver or other personnel directly. The complaining process (F_{17}) occurs mostly via telecommunication devices (e.g. using video call or writing a message). The most significant alteration is foreseeable in the communication between the 'vehicle'

and other participants, especially passengers (F_{18}). The human reactions, mimicry, eye movement, gesticulation play important role in the current traffic. In the future, the vehicle has to indicate its intention unambiguously /$l_{18}=5$, $C_{18}''=625$/. However, the communication comes about via electronic devices. The vehicles recognize each other's, pedestrians' and bikers' location (if they have e.g. smart phone), and can warn all the participants in this way. The entertainment (F_{19}) (browsing on the internet; wireless charging of personal devices) during travel becomes more important, which is also consequence of exemption from driving. Delay-insensitive downloads (DID) enable downloading multimedia content (e.g. audio, video, movies) requested by users (Karagiannis et al., 2011). Role of function seat reservation (F_{21}) becomes more significant. as future mobility is more pre-planned, travelers have to be more conscious. Functions regarding payment, ticketing and check-in (F_{22}, F_{23}, F_{24}) require less direct human acts, however more touching /$a_{4,22}=2$, $a_{4,23}=a_{4,24}=1$/ and typing actions /$a_{5,22}=2$/ (e.g. e-ticketing, using vending machine). Validation of the ticket (F_{24}) becomes more simple (less touching) or entirely automatic /$l_{24}=3$/ (e.g. by tracking user). However, in special cases control of the entitlement (F_{25}) requires human inspectors aided by advanced devices /$l_{25}=2$/.
The CCTV surveillance and advanced sensor technology have important role to prevent safety critical situations. These situations and technical failures should be recognizable by implemented sensors and automatic image processing or remote monitoring by humans. The function of avoiding accidents between vehicle and passengers (F_{31}) is currently the most critical issue in regards of autonomous vehicles /$l_{31}=2$, $C_{31}=490$/. The entire boarding process becomes automatic (door opening/closing and warning), however these systems are rather common (F_{32}) /$l_{32}=1$/. The most safety critical functions (F_{33}, F_{34}, F_{35}, F_{36}, F_{41}, F_{42}) require automatic machine recognition, strict regulations, elaborated intervention plans and fast human actions /$l_{33}=l_{34}=l_{35}=3$, $l_{36}=l_{41}=l_{42}=2$/. The sense of security can be improved by implementation of more static emergency call devices (F_{43}). Avoiding hacking and terrorist attacks require advanced identification of suspicious persons (F_{44}). Management of the passenger room/cabin conditions (F_{51}) becomes completely automatic in the future /$l_{51}=3$/. According to defined rules the machine switches on/off the devices (e.g. heating) based on sensor data. Cleaning processes of the vehicle do not change, however, dirty room is recognized by remote monitoring or passenger complains (feedbacks) via electronic devices. After travel the complaining (F_{61}) mostly does not require personal contact, however, it cannot be eliminated entirely /$l_{61}=2$/. Handling lost belongings (F_{63}) is also changing; travelers should be more aware of its risk and inform the remote monitoring services about the belongings. Data collection from/about passengers (F_{64}) becomes highly automatic if user gives permission. If a passenger provides data, he or she may receive more value-added information. Data collection from/about vehicle/infrastructure (F_{65}) becomes also highly automated.
In the future eyesight still remains significant but its usage intensity slightly decreases. Most relevant reduction can be noticed in operations by hand /$AA_7=-0.49$/ (less direct contact – e.g. during ticket validation). As the significance of smart mobile devices increases, the requirements towards the related human abilities rise. Vibration sensing will be eight times more relevant than nowadays. Significant increasing is expected in touching /$AA_4=+0.39$/ (e.g. during entertainment, boarding), and typing /$AA_5=+0.24$/ (e.g. using personal mobile devices during seat reservation, journey planning, etc.). Whereas sensing abilities alter differently, the required human cognitive capability all in all reduces /$AA_9=-0.22$/, as the machine support is growing. The human thinking (e.g. route planning) is in many cases replaced by machine.
The personal interactions of human personnel groups are particularly needed in case of special passenger groups (e.g. disabled, elderly or technically underdeveloped persons) and situations (e.g. foreign passenger in an unknown city). Therefore, employment of personnel in some functions is more effective than an automated solution (F_{17}, F_{22}, F_{23}, F_{61}, F_{63}). Handling of emergency and security situations (F_{33} – F_{37}, F_{41} – F_{43}) also require human interventions, however, the recognition of these situations can be appreciably automatized. Autonomous functions must be supervised by humans. The attendants' processes are aided by machines, so the number of humans may decline and their operation processes are more efficient (less wrong decisions, faster decision making). The personnel of future public transportation consist of:

- dispatchers: their processes are already currently aided by advanced infocommunication procedures, however some decision cannot be programmed. In the future dispatchers remain as a supervisor.
- supervisors: security attendance and information provision by human presence is important at eventful passenger facilities. Their tasks are broadened with former driver tasks (e.g.: checking cleanness in the vehicle).
- customer service: their role remains significant as several situations require human contact.
- security team: although image recognition systems reliably recognize the critical situations they are unable to interact. Therefore, quick moving human security teams are necessary (e.g. remove abandoned package).
- rescue team: in case of any emergency situation humans can more easily guide the passengers (e.g. during evacuation) and the medical interventions also require personal presence.

6. Conclusions

The main contribution of the research is the elaborated analysis method of passenger handling functions. In this method safety issues, automatization potential, frequency of function usage and human abilities are mapped by parameters. The method is applicable to determine indicators which fairly describe the automatization potential of the functions and the implied alteration of abilities. It has been found that the required eyesight as an ability and the cognitive capability slightly reduce, however, the relevance of vibration sensing, touching and typing significantly increases. In the future travelers receive value-added information and guidance from more sources; some human sensing becomes more intensive, but intensity of cogitation reduces. Less personnel are sufficient and most of them are employed as supervisor. We faced that collection of passenger handling functions require system- and process-oriented approach. Determination of alteration of function caused difficulties as only a few scholar publications related directly to the future transportation and passenger handling functions are available. Our future research focuses on the supplementary operational functions (e.g. parking, cleaning, maintenance), as these functions influence directly the mobility service. The research question is the same, how they to be automatized. Furthermore, we intend to model the entire autonomous public transportation system and its operational processes from several aspects. For instance, one current relevant hot topic is, how do the demands and capacities alter and how the pure traffic situations are to be modelled and simulated.

Acknowledgements

The publication of the work reported herein has been supported by ETDB at BME.

References

Bąk, M.; Borkowski, P. 2015. Applicability of ICT Solutions in Passenger Transport - Case Studies from Different European Backgrounds, *Transport*, 30(3): 372-381. DOI: 10.3846/16484142.2015.1079552

Davidson, P.; Spinoulas, A. 2015. Autonomous Vehicles: What Could This Mean for the Future of Transport? In *AITPM*.

Esztergár-Kiss, D.; Csiszár, Cs. 2016. Multicriteria Analysis of Hungarian Journey Planners, *Periodica Polytechnica Transportation Engineering*, 44(2): 97-104. DOI: 10.3311/PPtr.8570

Földes, D.; Csiszár, Cs. 2016. Conception of Future Integrated Smart Mobility. In *Smart Cities Symposium Prague (SCSP 2016).* DOI: 10.1109/SCSP.2016.7501022

Fagnant, D.J.; Kockelman, K. 2014. The Travel and Environmental Implications of Shared Autonomous vehicles, using agent-based model scenarios, *Transportation Research Part C: Emerging Tech.*, 40: 1-13. DOI:10.1016/j.trc.2013.12.001.

Fagnant, D. J.; Kockelman, K. 2015. Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations, *Transportation Research Part A: Policy and Practice*, 77: 167-181. DOI: 10.1016/j.tra.2015.04.003.

Godoy, J.; Pérez, J.; Onieva, E.; Villagrá, J.; Milanés, V.; Haber, R. 2015. A driverless vehicle demonstration on motorways and in urban environments, *Transport*, 30(3): 253-263. DOI: 10.3846/16484142.2014.1003406.

International Transport Forum 2015. *Urban Mobility System Upgrade - How Shared Self-Driving Cars Could Change City Traffic*, Paris, France. Available from Internet: <http://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf>.

Kamargianni, M.; Li, W.; Matyas, M.; Schäfer, A. 2016. A Critical Review of New Mobility Services for Urban Transport, *Transportation Research Procedia*, 14: 3294-3303. DOI: 10.1016/j.trpro.2016.05.277.

Karagiannis, G.; Altintas, O.; Ekici, E.; Heijenk, G.; Jarupan, B.; Lin, K.; Weil, T. 2011. Vehicular Networking: A Survey and Tutorial on Requirements Architectures, Challenges, Standards and Solutions, *IEEE Commun. Surveys Tutorials*, 13(4): 584-616. DOI: 10.1109/SURV.2011.061411.00019.

Li, Z.; Chitturi, M.V.; Yu, L.; Bill, A.R.; Noyce, D.A. 2015. Sustainability effects of next-generation intersection control for autonomous vehicles, *Transport*, 30(3): 342-352. DOI: 10.3846/16484142.2015.1080760.

Nykl, J.; Hrncir, J.; Jakob, M. 2015. Achieving Full Plan Multimodality by Integrating Multiple Incomplete Journey Planners. In Proceedings of *18th International Conference on Intelligent Transportation Systems.* DOI: 10.1109/ITSC.2015.234.

Pribyl, O.; Horak, T. 2015. Individual Perception of Smart City Stategies. In *Smart Cities Symposium Prague (SCSP 2015)*. DOI: 10.1109/SCSP.2015.7181550.

Rao, J.; Giuli, T. 2011. Evaluating vehicular ad hoc networks for group applications. In Proceedings of *IEEE PerCom* 594-599. DOI: 10.1109/PERCOMW.2011.5766959.

Tettamanti, T.; Milacski, Z.Á.; Lőrincz, A; Varga I. 2015. Iterative Calibration Method for Microscopic Road Traffic Simulators, *Periodica Polytechnica Transportation Engineering*, 43(2): 87-91. DOI: 10.3311/PPtr.7685.

Winter, K.; Cats, O.; Correia, G., van Arem, B. 2016. Designing an Automated Demand-Responsive Transport System: Fleet Size and Performance Analysis for the Case of a Campus-Train Station Service. In *TRB 95th Annual Meeting*.

SUSTAINABLE TRANSPORT DEVELOPMENT STRATEGIES. CASE STUDY: EXTENSION OF THE PEDESTRIAN ZONE IN BELGRADE CENTRAL AREA

Milena Vukmirović[1]
[1] *University of Belgrade – Faculty of Architecture, Belgrade, Serbia*

Abstract: During the seventies, Belgrade mostly has developed in step with other European cities. This particularly refers to the creation of the pedestrian zone in the centre of the city, similar to those that at that period appeared in Paris, Munich and Vienna. The first idea of creating a pedestrian zone in the centre of Belgrade emerged in the early seventies, and was formally defined in the General urban plan from 1972 and later in the Regulatory Plan for the Central Zone of Belgrade from 1977. The fundamental reconstruction of Knez Mihailova Street and the Republic Square was carried out following the urban design project created by architect Branislav Jovin. The works started in May, and the street was open to pedestrians on 20 October 1988. By mid-2010, the majority of planned interventions of this kind have contributed to the formation of the pedestrian zone in the centre of city. Following the recommendations on sustainable urban development and the introduction of a new green hierarchy of urban transport, current development trends favour the further expansion of the pedestrian zone to the banks of the Sava and Danube. Bearing this in mind, the paper would present an overview of past and current efforts to apply the principles of sustainable development in Belgrade, discussed from the aspects of transport policy and concepts for creating a pedestrian-friendly environment.

Keywords: pedestrian zone, sustainable transport, sustainable development, city centre, Belgrade.

1. Introduction

The quality of life and the quality of the environment in cities are notably affected by road transport and traffic. Considering the main problems associated with increasing urban traffic and congestion, the negative impacts on urban quality of life could be emitted in the following domains: visual instruction, noise and vibration, energy consumption, severance, competitiveness, accidents, air pollution, loss of urban “living space”, economic efficiency and equity (European Commission. Environment Directorate-General, 2004). Following the statistics and some predictions, 80% of Europeans live in an urban environment; every year more than 3 million cars are added to the car fleet in Europe and total road traffic kilometres in urban areas will grow by 40% between 1995 and 2030. As the issue is identified, there is a need to find the solution that could be from the one hand increase the road space available for cars, while on the other, the reduction of the car capacity could represent a sustainable, efficient planning solution. The second solution than can contribute in he improvement of the quality of life and quality of the environment in cities.

More increasingly experiencing the negative effects of mobility, cities are opening up to innovative approaches and policies for creating sustainable mobility. Therefore, a large number of cities[2] have active sustainable mobility policies in place as an alternative to cars and also receive the support from EU in promotion and exchange of best practices in areas such as transport infrastructure, norm-setting, congestion and traffic management, public transport services, infrastructure charging, urban planning, safety, security and cooperation with the surrounding regions (European Commision, 2006).

Considering the sustainable mobility, the European Union’s Ministers of Transport adopted a definition[3] “that a sustainable transport system is one that: (1) allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promises equity within and between successive generations; (2) is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development; and (3) limits emissions and waste within the planet’s ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on land and the generation of noise” (European Union Council of Ministers of Transport, 2001).

Besides the general definition of sustainable transport, EU has adopted a series of documents called “Urban Mobility Package” in order to support measures in the area of urban transport by sharing experiences, show-casing best practices, and fostering cooperation, providing targeted financial support, focusing research and innovation on delivering solutions for urban mobility challenges and involving the Member States and enhance international cooperation (European Commission, 2015). The Package also includes A Concept for Sustainable Urban Mobility Plans (SUMP) that describes the main features of a modern and sustainable urban mobility and transport plan. In this paper special attention of SUMP is given to the element that covers the balanced and integrated development of all modes and on its topic on walking and cycling. This document was also used as an umbrella guideline in defining and developing the main principles for the proposal of the extension of the pedestrian zone in Belgrade central area.

---

[1] Corresponding author: milena.vukmirovic.arch@gmail.com
[2] London, Stockholm, Athens, Kaunas, Gdynia and other cities
[3] This definition was developed on the basis of the definition from 1997 by the Toronto-based Centre for Sustainable Transportation.

2. European Sustainable Urban Mobility Plan and Integrated Development of All Modes

The European Sustainable Urban Mobility Plan was developed on the basis of the broad exchange between stakeholders and planning experts across the European Union in order to describe the main features of sustainable urban mobility and transport plan. The Plan has defined goals and objectives, a long-term vision and clear implementation plan, an assessment of current and future performance, the balanced and integrated development of all modes, horizontal and vertical integration, participatory approach, monitoring, review and reporting and quality assurance (European Commission, 2013).

As a methodology recommended by the European Union the most of their cities has changed the concepts of urban development by reconstructing the centres and the entire urban transport system. In accordance with that the policy of changing the modes of transport in cities means more space for pedestrians, bicycles and public transport, a reduction of comfort for passenger cars. This situation is perfectly explained in the Manual for Streets (Department for Transport , 2007) as a hierarchy of traffic users with the purpose to assist in design, planning and development control decisions. The hierarchy places pedestrians at the top, followed by cyclists, then public transport, with unaccompanied private car users last (see Fig. 1).

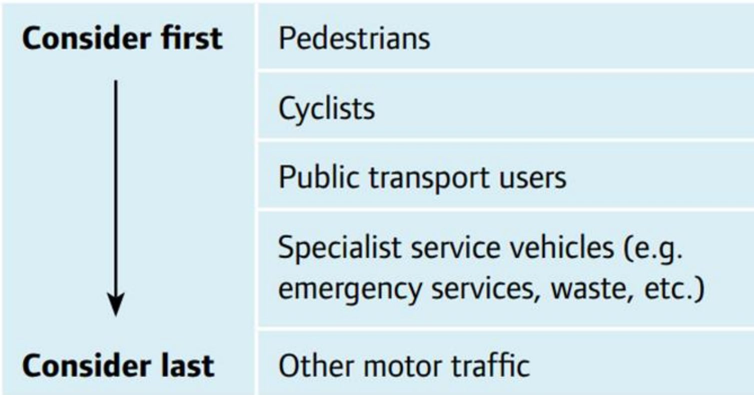


Fig. 1.
The hierarchy of traffic users (Department for Transport, 2007, p. 28)

The principles defined by using the hierarchy "sets objectives that ensure resilience and adaptability in the energy requirements of our transport network, with a focus on delivering societal needs. It pulls together policy proposals that demonstrate a consensus for this type of approach. The combination of cross-modal consensus and sound engineering makes this a powerful tool to achieve the step change needed to deliver a sustainable transport network" (Institution of Mechanical Engineers, 2013). Its creators also consider that it could be used in all governmental departments and businesses when making decisions on their transport choices in terms of both use and planning activities.

Following the principles of SUMP and transport hierarchy the goal is to change the function of transport for longer distances from car to public transport (metro, tram, bus, etc.) while for short distances to encourage the use of walking and bicycles. In addition to this there is a proposal for using the modes of transport based on energy from sustainable sources (electrical buses, electrical cars, etc.). It also proposes the introduction of car sharing system for those who need a short lasting automobile use in the city as well as park and ride for a combination of use od car for travelling out of the city and use of public transport for movement in the city.

The effects of these approaches are visible only if the entire politics in city urban and transport planning is based on the principles of SUMP. As one of it's the most recognisable manifestation is the plan to implement car-free strategies, which can be recognised in many European cities.

2.1. European cities with plans to go car-free

Although it dates back to the seventies, the city plans to go car-free are very actual in recent years. Starting with 2014 several European cities have announced their ambitions to convert parts of their central districts into pedestrian oriented places with less automobile congestion and air pollution. They include Paris, Madrid, Oslo, Milan, Dublin, and Brussels, while Belgrade has also announced its initiatives to extend the pedestrian zone in the centre of the city in mid-2015.

Concerned about the worsening air quality on the centre of the city, the **City of Paris** authorities has decided to keep odd-numbered cars out of central Paris for a single day on 17th March 2014. According to the data collected by Airpartif (2014) on that day, road traffic dropped by 18%, with drops of 13% in the area that surrounds inner Paris and 10% in suburbs. Compared with data from 10th March 2014 it was recorded the reduction levels of pollution by PM-10 within the city by 6%, with levels 10% lower than normal at rush hour on the Beltway. Nitrogen dioxide levels dropped by 10% overall, and by 30% on the Beltway at rush hour (Airparif, 2014). These and similar activities continued during the next two years with a tendency to build new pedestrian zone along the Seine and expand the zone of 30 km/h.

In 2012 the **City of Madrid** has adopted the revised version of General Urban Plan with the aim “to transform much of a car-snarled city centre into a leafy pedestrian's dream” (O'Sullivan F. , 2013). The Plan has foresaw the transformation of 24 major streets of Madrid in that way to remove car lanes, add bike lanes and trees and to put the new hierarchy in place where pedestrians come first, then public transport, then bikes, then cars. It also suggests additional steps to keep inner Madrid car-free, while parking places in central buildings will be strictly limited to encourage people onto public transport.

Dublin city also introduce the urban plan that aims to ban cars from the parts of the city centre until 2017. With these kind of measures the authorities are expecting “to reach a point where one in five people commutes into the core via private car, while the rest coming by transit (55%), bike (15%) or on foot (10%)” (Eric, 2015).

Similar to Dublin, the **City of Oslo** has also announced the plan with the goal to go car-free, banning the private cars in the central district by 2019. The city will enhance its bike infrastructure by building “at least 60 kilometres of bicycle lanes and give a “massive boost” to public transit” (Fouche & Solsvik, 2015). The “total pedestrianization of the historical centre” is the aim of the **City of Milan** local authorities. Even if they do not have a clear timeframe for this action, this could be seen as a continuation of activities started with the introduction of an effective congestion pricing scheme in the core of the city.

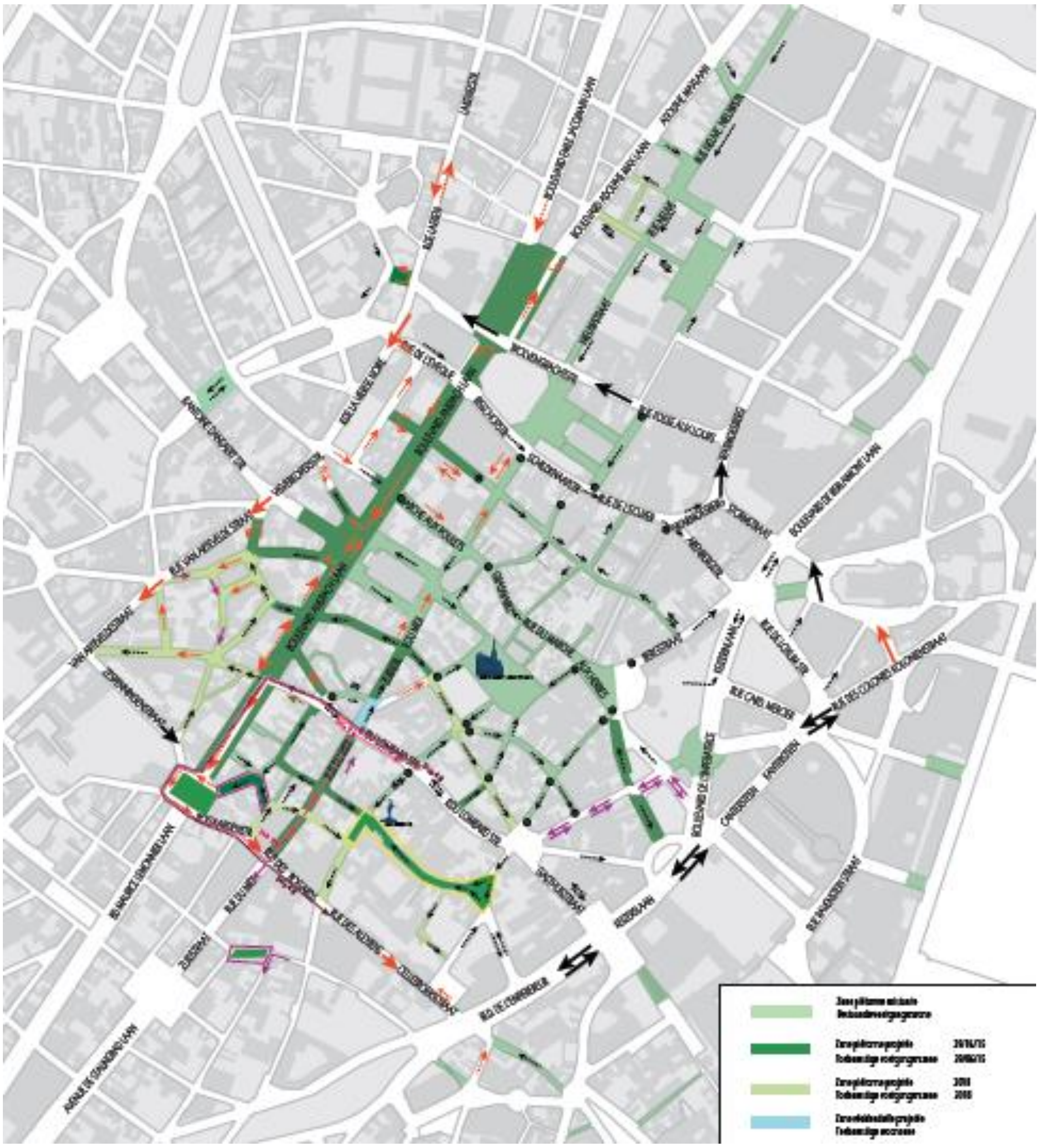


Fig. 2.
Brussels's pedestrian zone (City of Brussels, 2015)

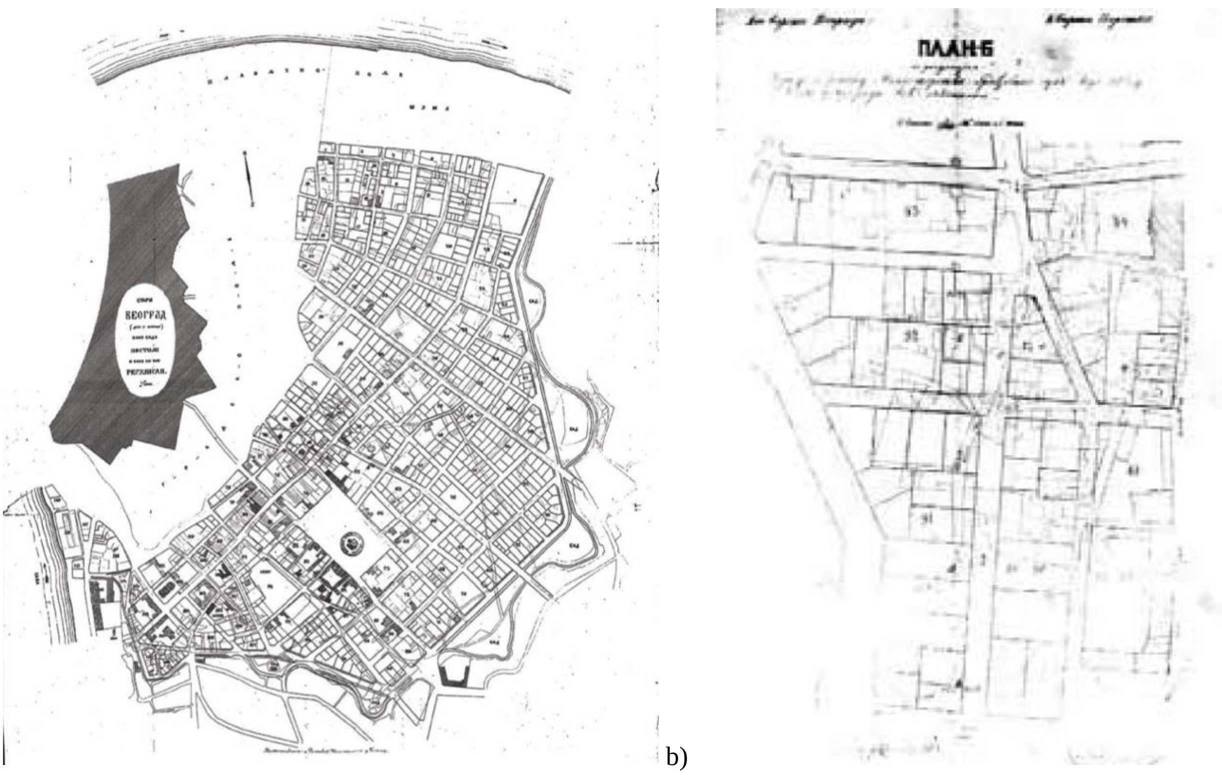
Known as the Europe’s most congested, the **City of Brussels** has a plan to turn the central axis into a pedestrian zone (O'Sullivan F. , 2014). That will contribute to the extension of the existing pedestrian zone almost double (from 28 to 50 hectares, see Fig. 2). The realization of this vision will cause that Brussels will have a pedestrian zone slightly lower than that in Venice. Similar to mentioned European cities, the local authorities of the City of Belgrade are working on the realization of the extension of the pedestrian zone in the city centre, based on the initiatives announced in mid 2015.

3. Extension of the pedestrian zone in Belgrade central area

In the same period when these changes occur in mentioned European cities and by analysing the overview of urban characteristics, open public spaces and quality of life of citizens and bearing in mind the current world trends in the field of urban planning and design, transport, protection and enhancement of natural and environmental surroundings and social development, the City of Belgrade initiated the project Identity_Mobility_Ecology (IME), which was adopted at the meeting of the City Council on April 9, 2015. The Project IME comprises 20 sub-projects whose implementation will enable to establish standards and rulebooks for design of open public spaces, use modern technology for unifying spatial data - GIS, establish new, environmentally acceptable hierarchy of traffic participants, restore facades, improve the city lighting, develop important open public spaces, markets and urban pockets and develop areas of historic and cultural significance. The fourth project titled as "extension of the pedestrian zone of Knez Mihailova street" includes "the implementation of multiple projects in order to further develop the pedestrian zone in the heart of Belgrade, which started in 1980" (Folic and Vukmirovic, 2015).

3.1. Historical background

The year 1867 is marked as the turning point in the history of the modern urban development of Belgrade. It is the year Emilijan Josimovic, the founder of modern Serbian urban planning and the first Serbian urbanist, completed his inventive urban plan of modern European Belgrade, which formed the basis of a survey that he started as an individual enthusiastic researcher. Today we refer to his yearlong work as the first modern urban plan of Belgrade, but it was actually Josimović's book on the reconstruction of Belgrade within the Moat in which he explained his proposal for new urban regulations with a plan in the scale of 1/3000 (see fig. 3a). His work was ordered to transform the oriental town into a European city (Terzic, 1997; Medakovic, 1997; Maksimovic, 1967).



a) b)

Fig. 3.
Emilijan Josimovic: a) Justification of the proposal to regulate that part of the town of Belgrade which lies in the moat using a lithograph plan, scale 1:3000 and b) Regulation of Knez Mihailova Street (Maksimovic, 1967)

According to Blagojevic, "Josimović was a contemporary to the famous European urbanists Haussmann and Cerdà, and his plan followed soon after their famous plans for reconstruction of Paris (1853-71), and Barcelona (1859-70). … He's plan demonstrates the universality of the European planning paradigm of the period, and more precisely of the ring principle which was employed in Vienna, yet it clearly brings out the specific character of Belgrade into its proposals for reconstruction." (Blagojevic, 2009, p. 31). Emilijan Josimović's work is of significant historical importance. The proposals and ideas from his book included, for example, connections between the fortress and the city. He proposed narrow roads realized through three gates, as a three additional passages into the new town. Most crucial for the life of the city is definitely the exit from Delijska (Knez Mihailova Street) to the Terazije (see fig. 3b). This new link emphasized the importance of Knez Mihailova Street, transforming it into a new trade centre.

The new interest for Knez MIhailova Street was aroused in late sixties and beginning of seventies when it came to drafting a new General Urban Plan of Belgrade. The new Belgrade Masterplan 1972 introduces a new, modern concept of transportation planning in the city based on the massive public transport system – metro, as well as planning of the pedestrian zones. This can be characterized as a partial continuation of a European trend of this time, having in mind that the first pedestrian streets in Europe were constructed between 1972 and 1978 (Vukmirović, 2013, p. 469). The conceptual design was made for the pedestrian zone in the city centre, the pedestrian boulevard of New Belgrade and the pedestrian street in Zemun. Belgrade got its first pedestrian street in 1988 on the basis of the regulatory plan of the Central zone of Belgrade from 1977.

Fig. 4.
Knez Mihailova Street - Before and after the transformation into the pedestrian street

The fundamental reconstruction of Knez Mihailova Street and part of Republic Square was carried out according to the project of architect Branislav Jovin. Work started in May, and the street opened to pedestrians on 20 October 1988. According to Ferenčak, converting Knez Mihailova Street into a pedestrian zone was one of the few large urban themes that were brilliantly realized, bearing in mind that Belgrade had not developed enough in the areas of planning and continuity (Ferencak, 2008). The Regulatory Plan for the Central zone of Belgrade from 1977 envisaged the formation of a pedestrian zone, i.e., a network of pedestrian streets, but by 1988 only part of the plan was realized (Vukmirović, 2013, p. 358). Expansion of the Knez Mihailova street pedestrian zone continued in 2008, after which 9 more streets were completely or partially pedestrianized (according to the Plan from 1977). Following this trend, but significantly more ambitiously, in 2015 it continued with the IME project: Identity_Mobility_Environment (Folic and Vukmirovic, 2015). The project envisages the expansion of the Knez Mihailova street pedestrian zone and includes the full implementation of the Plan of 1977, which would make a complete entity with the focus as Knez Mihailova street and continued expansion of the pedestrian streets towards the bank of the Sava on one side and towards Dorćol, that is the bank of the Sava, on the other.

3.2. Contemporary period

Extension of the pedestrian zone of Knez Mihailova Street includes implementation of multiple projects in order to further develop the pedestrian zone in the centre of the city. In this way, the City will develop “a green network” of pedestrian spaces in the city centre, which would interconnect the existing public spaces and spatial units of a broader significance for the urban identity all with the aim to reduce the use of private cars for transport and to create greener, healthier and more pleasant living space. The project will be realised in four phases that are temporarily and spatially defined (see Fig. 5).
First phase of the project covers public spaces with the total area of 35.272m2 (see Fig. 5, blue). Small part of this area is now in the phase of realisation (started in July 2015) and they will be reconstructed on the basis of the initial project for the pedestrian zone of Knez Mihailova street design by arch. Branislav Jovin during the eighties. Other parts of this area need to designed (that is planned to be during the first quarter of the 2016) and realised until the end of 2018. Second phase would be done simultaneously with the first phase. It includes the area of 10.149m2 located on the territory of Kosancicev venac, which is under cultural heritage protection as an ambience ensemble (see Fig. 5, rose). It also needs to be designed following strict conditions of the cultural heritage protection (that is planned to be during the first quarter of the 2016) and realised until June 2017. Third phase of the project includes street network in the area of Savamala district (see Fig. 5, green) with the total area of 4.405m2. It will be conducted within the realisation of Belgrade Waterfront project. Finally, the fourth phase envisages the reconstruction of streets and public spaces along Vasina and Uzun Mirkova Streets with the total area of 39.088m2 (see Fig. 5, purple). This area needs to be designed (that is planned to be during the first quarter of the 2016) and realised until the end of 2019.
As it can be seen, the phases are determined on the basis of the character and status of the territory, which would in the future result in the creation of four distinctive wholes: zone of hospitality (Toplicin venac with associated streets), zone

of history (Kosancicev venac), zone of culture (the path along Vasina i Uzun Mirkova Streets with Students' square and Plateau in front of the Faculty of Philosophy) and trade zone (Knez Mihailova Street).

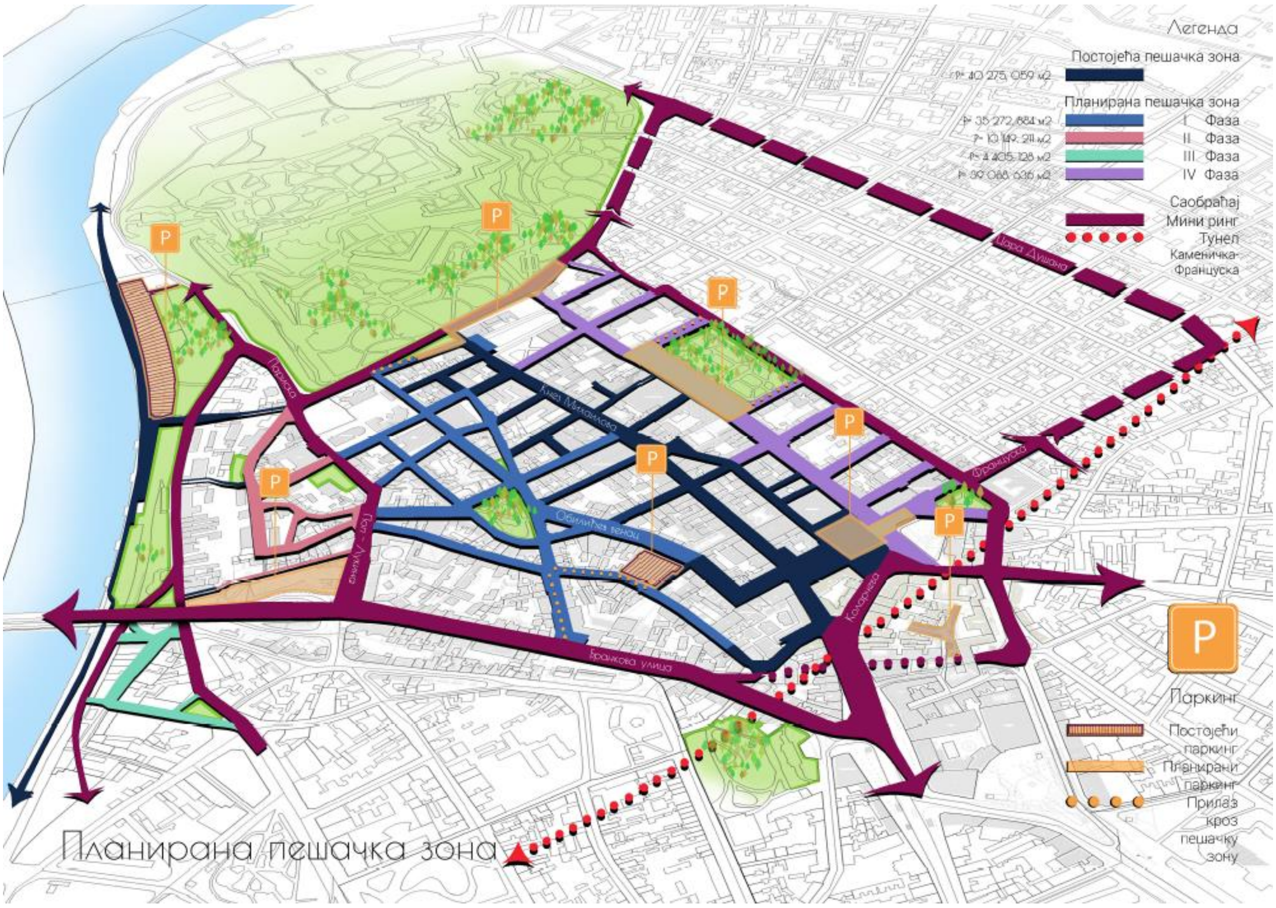


Fig. 5.
Concept of the extension of the pedestrian zone around Knez Mihailova Street. (Projekat IME: Identitet_Mobilnost_Ekologija Grada Beograda, 2015)

For the purposes of verification and further elaboration of this concept, the city authorities conducted two documents - Spatial-ecological valorisation of the future pedestrian zone of Belgrade (Glumac at al. 2015) and Feasibility study of enlargement of pedestrian zone Knez Mihailova Street (CEP 2016). According to the valorisation (Glumac at al. 2015), the extension of the pedestrian zone Knez Mihailova Street is the "most effective way of achieving environmental protection from the consequences of intense traffic, primarily for protection against noise and air pollution with the aim to reduce its level of the central zone of the city". On the other hand, the study (CEP 2016) provided different dimensions and variants of the project implementation. The study included different kind of analyses and produced three possible alternative solutions. The expert team used different methodologies form literature review, good examples of different pedestrian zones as a case studies, direct surveying of residents and car owners, models of intensity of transport, etc. The Study also defined different goals and visions: general conditions of bicycle transport in the centre of the city, logistic inside the area of pedestrian zone, smart functioning of the garbage disposal system, organisation of the public events, development of the GIS database, functioning of the taxis and functioning of the touristic transport. In this way, both documents reflect a general positive attitude with regard to this project and initiative.

3.3. Development of particular public spaces

The first segment of the project – the reconstruction of Vuka Karadzica Street was finished and officially opened in December 2015. It was done in accordance with the project by arch. Branislav Jovin. The project dated form the fist phase of the reconstruction of the street (1986th). The second segment of the project – the reconstruction of the Plateau of the Red Rooster (Crveni Petao) was finished and officially opened in April 2016, while the third segment, Zmaj Jovina Street was reconstructed in August 2016. It was also done in accordance with the project by arch. Branislav Jovin. In May 2016, the same team gave the final proposals for the area of Oblicev venac (see Fig. 6). The reconstruction of this area will start on 3rd September 2016.

Fig. 6.
Concept of the reconstruction of Obilicev venac and associated streets designed by Arch. Sinisa Temerinski i Arch. Branislav Jovin

The second phase of the pedestrian zone extension will cover the areas on the sides of the existing zone. It will be developed in the form of reconstruction and improvement of individual open public spaces and paths with the tendency to establish a connection with the riverbanks of Belgrade – (on Sava and Danube). The team that will deliver the public space design proposals is lead by Prof. Boris Podreka and the interventions will include four segments (see Fig. 7). The first segment covers the path form along the Vasina and Uzun Mirkova Streets with the focal points – public spaces that will be formed on Students' Square and Plateau in front of Faculty of Philosophy. Segment two is belongs to the Toplicin venac with its associated streets. The main public space in this area will be actual Park of Vojvoda Vuk with specially design area for children. The space on the place of the ruined National Library on Kosancicev venac is seen as an historical, memory labyrinth and it belongs to Segment three. The fourth segment is defined by the path along Sremska and Marsala Birjuzova Street, one of the busiest pedestrian connections between Knez Mihailova Street and area Zeleni Venac.

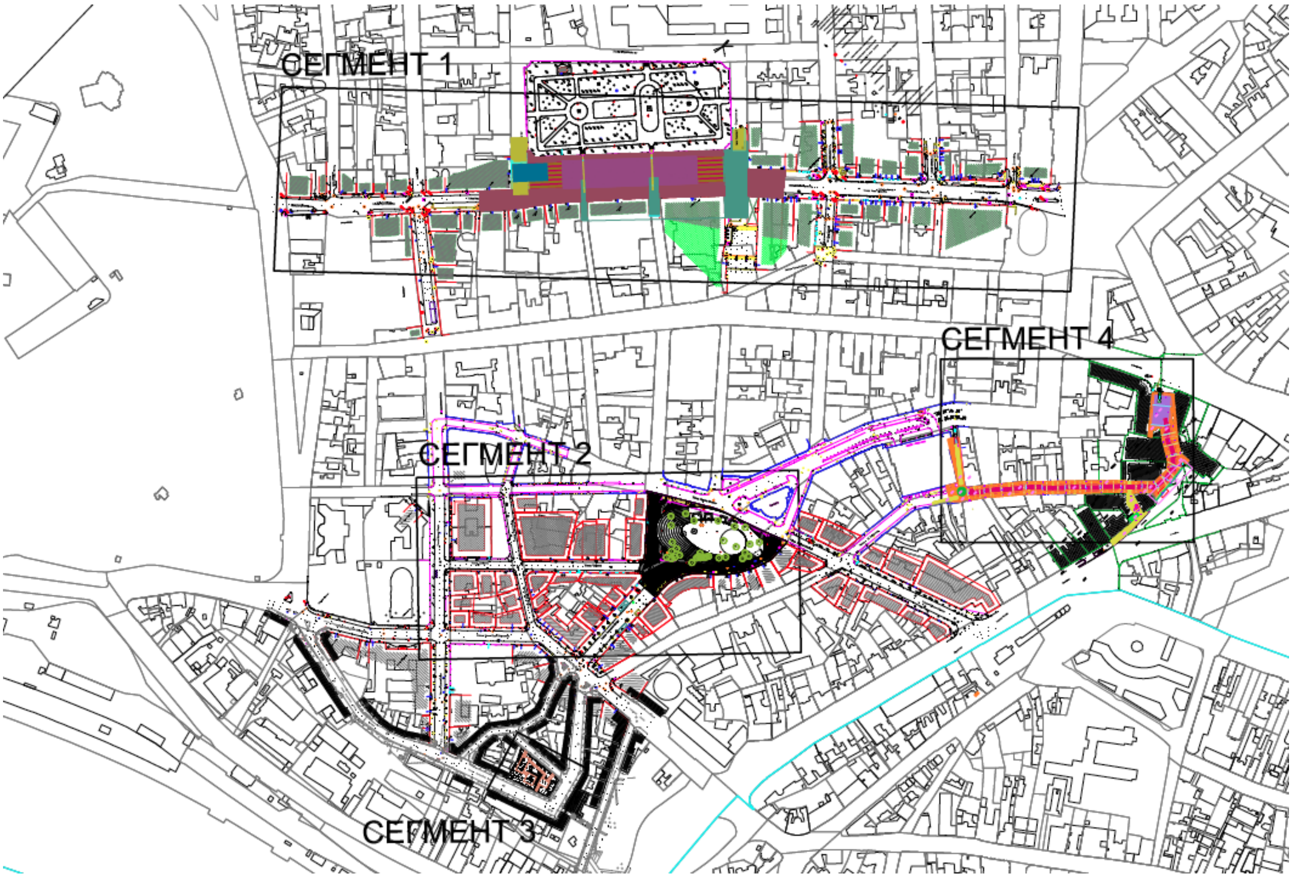


Fig. 7.
Design proposals for the segments. Source: the team lead by Prof Podreka

The functioning of the new pedestrian zone will be possible by introducing a transportation ring (see Fig. 5) for public transport, service and automobile use (most of it will belongs to zone 30km/h). On the other side, the access gates to the pedestrian zone (for public transport and private cars) are planned on the locations of the public transport stops and the planned locations for the new public garages. For the purposes of the movement of old and disable people as well as delivery, the new electric cars that could be moved in circles in the zone will be introduced.

4. Conclusion

Presented initiatives and realisations in order to extend the existing pedestrian zone in the core of the city are completely in line with the actual initiatives and plans of the leading cities in Europe. The guidelines that were proposed by European Union in relation to Sustainable Urban Mobility Plan have proved to be feasible and that achieve the expected results. Although it is considered as ambitious and which implementation will take several years, the project of the extension of the existing pedestrian zone in Belgrade has real potential which is positively evaluated by two studies. However, the expected functioning of pedestrian zone and implementation of the new transport hierarchy is possible only if the entire politics in city urban and transport planning is based on the principles. This can complicate the particular situation in Belgrade, because it still has need for an independent massive transport that was planned in seventies, but the question is what will be its final form.

5. Acknowledgements

This paper is the result of the scientific project No. 177009 – Modernisation of Western Balkans financed by Ministry of education, science and technological development of the Republic of Serbia.

6. References

Airparif 2014. Circulation alternée le 17 mars 2014. Retrieved 07 2016, 26 from Airparif. Available from Internet: <http://www.airparif.asso.fr/actualite/detail/id/112>.

Blagojevic, L. 2009. Urban regularisation of Belgrade, 1867: Trace vs. Erasure. *SAJ - Serbian Architectural Journal,* 1: 27-44.

City of Brussels 2015. Access to a pedestrian zone. Retrieved 07 26, 2016 from The City of Brussels. Available from Internet: < https://www.brussels.be/artdet.cfm?id=6742>.

CEP 2016. *Studija izvodljivosti proširenja postojeće pešačke zone Knez Mihailove ulice*. Studija izvodljivosti, CEP, Beograd (CEP. 2016. *Feasibility study of enlargement of pedestrian zone Knez Mihailova street*, Feasibility study, CEP, Belgrade)

Department for Transport 2007. *The Manual for Streets*, Thomas Telford Publishing, London, UK.

European Union Council of Ministers of Transport 2001. *Strategy For Integrating Environment And Sustainable Development Into The Transport Policy*, European Union Council of Ministers of Transport, Luxembourg.

European Commission 2006. *Communication from the Commission to the Council and the European Parliament - Keep Europe moving - Sustainable mobility for our continent - Mid-term review of the European Commission's 2001 Transport White paper*, European Commission, Brussels, Belgium.

European Commission 2015. Urban Mobility Package-Mobility and Transport-Clean transprt, Urban transport. Available from Internet: <http://ec.europa.eu/transport/themes/urban/urban_mobility/ump_en.htm>.

European Commission 2013. *A Concept for Sustainable Urban Mobility Plans*, European Commission, Brussels, Belgium.

European Commission-Environment Directorate-General 2004. *Reclaiming city streets for people: chaos or quality of life?*, Office for Official Publications of the European Communitie, Luxembourg.

Eric, J. 2015. 6 Big European Cities With Plans to Go Car-Free. The CityLab. Available from Internet: <http://www.citylab.com/cityfixer/2015/10/6-european-cities-with-plans-to-go-car-free/411439/>.

Ferencak, M. 2008. Miodrag Braca Ferenčak, poznati urbanista – „gde ćeš, sine, baš na arhitekturu?". Available from Internet: <http://www.ekapija.com>.

Fouche, G.; Solsvik, T. 2015. Oslo aims to make city center car-free within four years. Yahoo News. Available from Internet: <https://www.yahoo.com/news/oslo-aims-city-center-car-free-within-four-124930728.html?ref=gs>.

Folic, M.; Vukmirovic, M. 2015. *Projekat IME: Identitet_Mobilnost_Ekologija Grada Beograda.* Beograd: Grad Beograd - Sluzba za informisanje (Folic M.; Vukmirovic M. Project IME: Identity_Mobility_Environment, City of Belgrade - Department for Communication Belgrade, Belgrade, Serbia).

Glumac S.; Sterđević, B and Košpić S. 2015. *Prostorno-ekološka studija buduće pešačke zone Beograda*. Prostorno ekološka valorizacija, Beograd: Grad Beograd – Sekretarijat za zaštitu životne sredine (Glumac S.; Sterđević, B and Košpić S. 2015. *Spatial-ecological study of the future pedestrian zone of Belgrade*. Spatial ecological valorization, City of Belgrade - Secretariat for Environmental Protection, Belgrade, Serbia).

Institution of Mechanical Engineers 2013. Transport Hiearchy. Institution of Mechanical Engineers. Available from Internet: <https://www.imeche.org/policy-and-press/reports/detail/transport-hierarchy>.

Maksimovic, B. 1967. *Emilijan Josimovic - prvi srpski urbanist.* Beograd: IAUS (Maksimovic, B. 1967. Emilian Josimovic - the first Serbian urbanist, IAUS, Belgrade, Serbia).

Medakovic, D. 1997. *O Emilijanu Josimovicu (izabrani tekstovi).* Beograd: Drustvo urbanista Srbije (Medakovic, D. 1997. About Emilijan Josimović (selected texts), The Association of Serbian Urbanists, Belgrade, Serbia).

O'Sullivan, F. 2014. Europe's Most Congested City Contemplates Going Car-Free. The CityLab. Available from Internet: <http://www.citylab.com/commute/2014/01/europes-most-congested-city-contemplates-going-car-free/8027/>.

O'Sullivan, F. 2013. Madrid's Big Plan to Swear Off Cars. The CityLab. Available from Internet: <http://www.citylab.com/commute/2013/12/madrids-big-plan-swear-cars/7744/>.

Terzic, D. 1997. *Emilijan Josimovic, vizionar ulaska Beograda u urbanu civilzaciju.* Beograd: Drustvo urbanista Srbije (Terzic, D. 1997. Emilian Josimovic, visionary entering Belgrade in Ubani civilization. The Association of Serbian Urbanists, Belgrade, Serbia).

Vukmirović, M. 2013. *Značaj i uloga mreže pešačkih prostora u generisanju kompettitivnog identiteta grada.* Doktorska disertacija). Beograd: Univerzitet u Beogradu - Arhitektonski fakultet (Vukmirovic M. 2013 The role and the importance of pedestrian spaces in generating the comeititve identity of the city, PhD Thesis, University of Belgrade – Faculty of Architecture, Belgrade, Serbia)

BENCHMARKING TOOL FOR BIKE SHARING SYSTEMS

Tamás Mátrai[1], Péter Mándoki[2], János Tóth[3]
[1,2,3] BME Department of Transport Technology and Economics, Budapest, Hungary

Abstract: This paper presents the first application of a recently developed benchmarking methodology. Based on the existing practices this article proposes a multi-criteria analysis method for the assessment of PBS systems from user and operator perspectives. System performances differ from user and operator perspective. Best systems show diverse characteristics.

Keywords: bike sharing, benchmark, multi criteria assessment.

1. Introduction

According to UN forecast, the world population in mid-2015 was of about 7.3 billion people and by 2050 will reach 9.7 billion. Along with this urbanization is expected to increase (Buzási and Csete, 2015). One of the main goals of EU transport policy (European Commission, 2011) is to "halve the use of 'conventionally-fuelled' cars in urban transport by 2030; phase them out in cities by 2050". This means that car technology must be improved and clean transport modes must be preferred. EU transport policy also declares the necessity of urban mobility plans. These plans have to facilitate walking and cycling as transport modes. In urban areas the development of the infrastructure of non-motorized transport modes should have priority.
Cycling is one of the fastest developing sustainable transport solutions. With the spread of Public Bike Sharing (PBS) systems it is very important to understand the differences between a wide range of PBS systems. In order to do that we need to gather information about different measures. Active travel measures collected in different projects such as FLOW (Koska et al., 2016). The authors went through the available literature in their previous papers (Mátrai and Tóth, 2016a; Tóth and Mátrai, 2015; Mátrai and Tóth, 2016b), but since then some additional literature review has emerged (Fishman, Washington and Haworth, 2013; Fishman, 2016; Brown et al., 2016), which are comprehensive.
A complete framework has been developed during a doctoral research for analysing, comparing and categorizing public bike sharing systems. The first level of the methodology is gathering data about existing systems. The second level of the methodology compiles a SWOT analysis for each clusters based on the examined systems. The third level is a benchmark tool which supports the evaluation of systems. The fourth level of the methodology is the impact analysis and impact assessment.
This article focuses on the third level: a multi criteria assessment (MCA) for PBS. We summarize the already existing MCA methods in Chapter 2. Based on the existing practices this article proposes a benchmarking method of PBS systems from user and operator perspectives (see Chapter 3). Additionally, a test of the proposed system will be performed through a case study (see Chapter 4). At the last part of this article introduces future research steps and conclusions have been drawn.
The main idea behind this paper comes from the Urban Mobility Index developed by Arthur D. Little (Van Audenhove, Dauby, Korniichuk and Pourbaix, 2014). As the results can be different depending on whether the user's point of view or the operator's point of view is given priority, it is necessary to create two distinct lists. Based on the literature review of different MCA methodologies, the most appropriate has been selected. A shortlist of parameters has to be collected for both viewpoints. Parameter selection is based on expert judgment and results from a questionnaire. Different weighting methods were used and the most appropriate one has been chosen.

2. Literature review

Evaluation methods are used in almost all segments of the economy in the European Union. The European Conference of Ministers of Transport (ECMT, 2004) suggests various analytical procedures to use in transport investment assessment: multi-criteria analysis (MCA); value assessment; cost-benefit analysis (CBA); tariff assessment.
Comparing methods, such as the MCA, assess different competing alternatives, as opposed to method assessing only a single solution relative to absolute values. The most used comparing method is the MCA or benchmarking (Rapcsák, 2007; Gyarmati, 2003; Kukadapwar and Parbat, 2016). There are three main MCA methods that we discuss here, all other methodologies can be categorized under this three: general comparing method; compensatory MCA; outranking MCA (Mándoki, 2005; Magyar et al., 2000).

2.1. Comparing methods

The aim of comparing different alternatives is not always to determine an absolute scale, especially when only limited data are available. In this case a method is necessary which can provide quick and easy to understand results without

[1] Corresponding author: tamas.matrai@mail.bme.hu

weighting. From these methods the most known are the following, which only differ in the presentation methods (Kindler and Papp, 1975, 1977):

- Harris method: the different alternatives are assessed in a four point based scale. The result shown in a table,
- Marting method: the different alternatives are assessed in a four point based scale. The results are presented in a diagram.

The quick results and easy presentation is the advantages of these methods, however they have some limitations. Since they do not use any weighting it can be used only for similarly important criteria. This significantly narrows the field of its scientific application, usually it is used for marketing purposes.

2.2. Outranking methods

As these methods are using a simple weighted average they do not need any complicated methodology or computer programme. The main difference in these are the selection of criteria and their weights. The weights should be defined using as large sample as possible. Two distinct method should be mentioned here, but all the others has similar logic:

- Kesserling method: In this methodology the points in each criterion can be discrete values between 1 and 4 while the weights are between 2 and 10. This method calculate multiplication sum of the weights and points for each alternative, but divide it with the theoretically best alternative. It is immediately providing information not only the ranking of different alternatives, but also about how far are these from the theoretically best one. The scale of the alternatives is between 0 and 1, where 1 is the theoretically best alternative,
- Combinex method: In this method the point in each criterion can be between 30 and 80. The best alternative gets 80, the worst gets 30 while the middle ones calculated based on linear interpolation. There are no restrictions for the weights. The final combinex score of the alternatives are the multiplication sum of the points and the weights. These scores not only show the ranking, but also shows the gap between different alternatives. It is one of the easiest multi-criteria assessment method.

Comparison with these methodologies provide good results with careful preparation. The biggest problem can be in the appropriate selection of weighting factors. If these are not available in advance, they only can be obtained via questionnaires with experts. If these experts are not evaluating the weights in the same way, the results can be uncertain. The results can be manipulated easily if the weights are changed, which can cause confusion in the decision makers if the results are close to each other. In this case this method is not recommended.

2.3. Compensatory methods

In order to simplify the ranking of different alternatives and to provide some procedure there are several methods exist, from which four are presented here, since these are the most used one in the Hungarian literature:

- KI-PA method: In this method the points in each criterion is between 0 to 10. The weights are independent and their sum is equal to 1. This method uses preference and disqualifying factors. The preference (advantage) factor shows how much “A” alternative is better or equal then “B” alternative in percent. The disqualifying factor shows how big is the difference from the best alternative and it only takes into account the largest difference. The comparison is done for each pair, which is the largest deficiency of this method – which was developed by Hungarian authors – since the final ranking is not always obvious,
- ELECTRE: This ranking method is using importance coefficients and the veto thresholds. Veto threshold exists in each criterion. The decision can be made with the help of ranking and veto threshold. This method is different if the aim is to choose, rank or sort. It usually used in the first place in order to create a subset of feasible alternative, then another MCA method is used,
- PROMETHEE - GAIA: This method is based on solely preference factors. It uses progressive ranking, from which a clear ranking can be provided. This method compares the alternatives in each criterion. It also equipped with high level sensitivity analysis and graphical representation,
- AHP (Analytic Hierarchy Process) method (Saaty, 2008): This method using a hierarchical tree method for graphically represent the decision process. The highest level is the aim, under which the criteria and sub-criteria has been written. The alternatives are in the lowest level. The main difference from the above mentioned methods is that AHP uses a common utility function where all the preferences are combined, while the European ones are using alternative pairs for this purpose.

All compensatory methods use some kind of weighting in order to determine the preferences of the evaluator. This method called compensatory, since it provides a possibility for compensation based on the different weights between criteria. The determination of these weights are important since the impact of these on the final results is huge. The weight of a criterion represents the increase in the global score associated to a swing in that criterion between the worst and the best level. The ratio between the weights of two criteria represents the trade-off between these criteria.

There are several different method exists for determining the weights in these assessments. All methods are based on judgments by the decision maker (Oliveira, 2010). The four main types are the following in a structured way:

- Require quantitative judgment: in these methods the decision makers need to understand the difference between each criteria and need to know their possible scale and their desired value: swing weights method, trade-off method,
- Require qualitative judgment: in these methods the decision makers should choose between pairs of alternatives and the system automatically compute the weights based on the answers: MACBETH, AHP

2.4. Urban Mobility Index

In 2010 Arthur D. Little launched its first publication in this topic called "Future of Urban Mobility" in this study the company presented its method call Urban Mobility Index, which assess the performance and maturity of transport and mobility in cities. They analysed 66 cities worldwide. From the research point of view, the importance of this index was its reproducibility, since all the weights and scoring algorithm has been published. Since then the company made a strategic agreement with UITP and they published the refined version of the Index. The number of cities involved reached 84 and are covering all continent. The assessment criteria expanded from 11 to 19.
Besides the easiness of use and the complete openness the calculation process of the index has some flaws. Due to the calculation process the scores are highly dependent on the selected cities. It means that without all the information from all assessed cities the process can be reproduced, but it might give us false results.

3. Methodology

MCA methods are easy to compute and widely used (Esztergár-Kiss and Csiszár, 2016). Based on the literature review in this assessment a compensatory multi-criteria analysis has been selected. The weight definition is based on an expert panel judgment with consensus building method. As the operator and the user perspective is different, two scale has been developed. The other important decision is the usage of scales. Since the authors cannot decide in advance which is better, both absolute and relative value function has been used and the difference analysed. In the relative scale the minimum and maximum point assigned to the worst and the best value of a PBS system in the sample, while in the absolute scale a theoretically worst and best value has been used at each sub-criteria. The point of a given system in given sub-criteria has been calculated with a linear interpolation between these limits (worst and best values).

3.1. Assessment from user perspective

The user perspective represented with 5 main criteria and all together 25 sub-criteria:
1. Coverage (Table 1): This main criterion represents how the system covers the city and the agglomeration. It combines geographic and demographic coverage,
2. Affordability (Table 2): This main criterion shows how affordable to use the system. It uses specific values based on average incomes and public transport fares,
3. Accessibility (Table 3): This criterion represents how easy to access the system. It uses sub-criteria which inform about the opening times and registration processes,
4. Innovation (Table 4): As innovation is an important part of the 4th generation systems, it shows how innovative the system is,
5. Integration and Sustainability (Table 5): Neither integration nor sustainability has enough sub-criteria, but when combined together their weight are equal to the other main criteria.

As the expert panel decided that all 5 main criteria is equally important the weights of each is 0,2 (or 20%).

Table 1
Sub-criteria in the Coverage main criteria

Sub-criteria name	**Weight**	**Worst**	**Best**	**Definition**
City coverage	5%	0	1	Ratio between the service area size and the city size
Agglomeration coverage	5%	0	1	Ratio between the service area size and the agglomeration size
Station density	5%	0	4	Ratio between the number of stations and the city size in km^2
Bike density	5%	0	10	Ratio between then number of bikes and the number of inhabitants in the city (in 1000 people)

Table 2
Sub-criteria in the Affordability main criteria

Sub-criteria name	Weight	Worst	Best	Definition
Specific cost of long term access	5%	0,05	0	Ratio between the cost of annual bike sharing pass and the average monthly income in €
Specific cost of short term access	5%	0,05	0	Ratio between the cost of daily bike sharing pass and the average monthly income in € divided by 20 workdays
Financial attractiveness of long term access	5%	2,5	0	Ratio between the cost of annual bike sharing pass and the monthly public transport pass which covering the entire city
Financial attractiveness of short term access	5%	20	0	Ratio between the cost of daily bike sharing pass and the public transport single ticket

Table 3
Sub-criteria in the Accessibility main criteria

Sub-criteria name	Weight	Worst	Best	Definition
Are there any date when it is closed?	5%	1	0	1 (Yes), it means that the system is closed in some days during a year 0 (No), it means that the system operates all day of the year
Are there any time period of the day when it is closed?	5%	1	0	1 (Yes), it means that the system is closed in some time during an operating day 0 (No), it means that the system operates 24 hours during an operating day
Can the system be used without registration for short term?	5%	0	1	1 (Yes), it means that the system can be used with a single credit card for short term and does not require any registration process in advance 0 (No), it means that a registration process requires in advance, which can be either in person or online
Does it necessary for personally go for registration for long term?	3%	1	0	1 (Yes), it means that either registration is not required or if it is required it can be done online 0 (No), it means that a registration process has to be finished in person in one of the user centres
Station functionality	2%	0%	100%	Ratio between the number of stations where all functions are available and the total number of stations

Table 4
Sub-criteria in the Innovation main criteria

Sub-criteria name	Weight	Worst	Best	Definition
E-bike availability	4%	0	1	Ratio between the number of electric bikes and total number of bikes
Are the docking stations mobile?	4%	0	1	1 (Yes), it means that the stations can be easily moved to another location without any construction 0 (No), it means that the stations cannot be moved to another location without construction activities
Can a helmet be hired?	3%	0	1	1 (Yes), it means that a helmet can be hired from the station 0 (No), it means that the stations cannot be moved to another location without construction activities
Are there an online, real time website to check station occupancies?	1%	0	1	1 (Yes), it means that an online, real time website exists to check station occupancies 0 (No), it means that an online, real time website does not exists to check station occupancies
Is it possible to pre-book a bike online?	4%	0	1	1 (Yes), it means that possible to pre-book a bike online 0 (No), it means that is not possible to pre-book a bike online
Different renting options	4%	0	11	The sum of the different renting options

Table 5
Sub-criteria in the Integration / Sustainability main criteria

Sub-criteria name	Weight	Worst	Best	Definition
PT fare integration	4%	0	1	1 (Yes), it means that bike sharing fare depends on the availability of public transport pass 0 (No), it means that there is no dependency between the public transport and bike sharing fare
User card integration	4%	0	1	1 (Yes), it means that a single user card exists for PT and bike sharing 0 (No), it means that there is no integrated user card exist for public transport and bike sharing
Are there any bonus-malus system available	4%	0	1	1 (Yes), it means that the usage fee depends on some parameters of the system (e.g. rent a bike from a full station is cheaper) 0 (No), it means that the usage fee is constant
Are there any renewable energy source for the stations?	4%	0	1	1 (Yes), it means that a renewable energy source used for the stations (e.g. solar panel) 0 (No), it means that the stations are using conventional energy sources
Are there any e-car used for the redistribution or maintenance?	2%	0	1	1 (Yes), it means that either during the redistribution or maintenance process electric cars have been used 0 (No), it means that no electric car used during the redistribution or maintenance process
Are there any bike used for the redistribution or maintenance?	2%	0	1	1 (Yes), it means that either during the redistribution or maintenance process bikes have been used 0 (No), it means that no bikes used during the redistribution or maintenance process

3.2. Assessment from operator perspective

The operator perspective represented with 5 main criteria and all together 24 sub-criteria:

1. Coverage (Table 1): This main criterion represents how the system covers the city and the agglomeration. It combines geographic and demographic coverage,
2. Affordability (Table 2): This main criterion shows how affordable to use the system. It uses specific values based on average incomes and public transport fares,
3. Usage (Table 6): This main criterion shows how much the system used both with long term and short term access types,
4. Opportunity (Table 7): This criterion provides information about the possibilities of the system. It combines demographic data with general information about the city,
5. Complexity (Table 8): This main criterion describes how complex a system from the operator point of view, how hard is to operate it.

As the expert panel decided that all 5 main criteria is equally important the weights of each main criteria is 0,2 (or 20%). The Coverage and Affordability criteria are the same as in the user perspective.

Table 6
Sub-criteria in the Usage main criteria

Sub-criteria name	Weight	Worst	Best	Definition
Long term user for each bike	4%	0	50	Ratio between the number of new annual pass holders in 2015 and the total number of bikes
Short term user for each bike	4%	0	365	Ratio between the number of daily access pass sold in 2015 and the total number of bikes
Average daily rent for each bike	4%	0	25	Ratio between the number of average daily rent in 2015 and the total number of bikes
Long term users	4%	0	25	Ratio between the number of new annual pass holder in 2015 and the number of inhabitants in the city (1000 ppl)
Short term users	4%	0	400	Ratio between the number of daily access pass sold in 2015 and the number of inhabitants in the city (1000 ppl)

Table 7
Sub-criteria in the Opportunity main criteria

Sub-criteria name	Weight	Worst	Best	Definition
Population	4%	0	10000	Total number of inhabitants in the city (1000 ppl)
Motorization	4%	0	1000	Vehicle ownership; number of cars per 1000 inhabitant, the values are for the country, not specifically for the city
Mode share opportunity	4%	0	55	Ratio between the modal split of public transport and modal split of cycling
Topography	4%	3	1	Topography of the service area categorized in the following three categories: 1 – flat; 2 – easy for cyclist; 3 – hard for cyclist
Helmet legislation	4%	0	100	Helmet legislation in the city for the following categories: 100 – No; 80 – Children only; 50 – Partial rules; Yes – 0

Table 8
Sub-criteria in the Complexity main criteria

Sub-criteria name	Weight	Worst	Best	Definition
Renting modes	4%	1	11	Number of different renting modes including the different mode in the station; at the docks; on the bike and on mobile device
PT fare integration	4%	0	1	1 (Yes), it means that bike sharing fare depends on the availability of public transport pass 0 (No), it means that there is no dependency between the public transport and bike sharing fare
User card integration	3%	0	1	1 (Yes), it means that a single user card exists for PT and bike sharing 0 (No), it means that there is no integrated user card exist for public transport and bike sharing
Are there any bonus-malus system available	3%	0	1	1 (Yes), it means that the usage fee depends on some parameters of the system (e.g. rent a bike from a full station is cheaper) 0 (No), it means that the usage fee is constant
Different usage rate for long and short term	3%	0	1	1 (Yes), it means that the usage fee is the same for short term and long term users 0 (No), it means that the usage fee is different for short term and long term users
Are there any electric bike?	3%	1	0	1 (Yes), it means that the system has some electric bikes 0 (No), it means that the system has no electric bikes

4. Application

As it was described in the previous papers (Mátrai and Tóth, 2016a; b) of the authors, a comprehensive database has been developed as part of a PhD research. From this database a dataset with nine systems has been selected in order to test the benchmarking methodology. The following list contains the main information about these systems, together with some aspect of the selection process:

1. **Mol-Bubi** (Budapest, HU): the first Hungarian system which belongs to the 4th generation. It is a small system with around 100 station and 1200 bikes. It has no e-bikes, but contains several innovative elements such as the on-boar computer, solar panels, GPS. The aim of the system was to promote cycling in Budapest. (http://molbubi.bkk.hu/),
2. **Santander Cycle Hire** (London, UK): it is London's self-service, bike-sharing scheme for short journeys, formerly called as Barclays Cycle Hire. It is a medium sized system with about 800 stations and more than 11 thousand bikes. It was established in 2010 as part of the Mayor’s Transport Strategy. (https://tfl.gov.uk/modes/cycling/santander-cycles),
3. **Vélib** (Paris, FR): it is one of the first bike sharing system which is well-known. It has more than 23 thousand bikes and more than 1800 stations located not only in inner Paris, but also in the suburbs. At least one station located in every 300 meters. It is one of the most known system which using the advertising company business model. (http://en.velib.paris.fr/),
4. **Bicing** (Barcelona, SP): this system especially targeting the local citizens, since it has no English website and the bikes cannot be hired without a personal registration. It has more than 400 station and 6000 bikes from which 150 is electric. (https://www.bicing.cat/),
5. **BiciMAD** (Madrid, SP): it is the first system which equipped only with electric bikes. The 165 stations and more than 200 bikes covering Barcelona inner city. It has a different pricing policy than the usual bike sharing systems, since the first 30 minutes is not free. (http://www.bicimad.com/),
6. **Citibike** (New York City, US): it is the largest system in the US. It is launched in 2013 with around 6000 bikes and 500 stations, but it is undergoing a large expansion in 2016 to reach 10 thousand bikes. It covers Queens, Manhattan, Brooklyn and Jersey City. (https://www.citibikenyc.com/),
7. **Capital BikeShare** (Washington DC, US): it works in the capital of the USA as well as Arlington, Alexandria and Montgomery County. It has more than 3000 bikes and 350 stations. It was the first bike share system in North America, which started in 2008 with 10 station and 120 bikes. The system itself is jointly owned by the participating jurisdictions and operated by a service provider. (https://www.capitalbikeshare.com/),
8. **Bixi** (Montreal, CA): this is the system with around 5200 bikes and 460 stations. The service area covers Montreal, Longueuil and Westmount. The system operator went bankrupt in 2014, but with the help of the municipality the system stayed in place. Since then it has successful expansion around the globe. (http://montreal.bixi.com/en),
9. **EcoBici** (Mexico City, ME): the system is in place in Mexico City, where the climate supposed to not the best for cyclist. It is created both for the citizens and tourists and started in 2010 with 84 stations and 1200 bikes. Currently it operates with 6000 bikes and 450 stations. Here the first 45 minutes is free. (https://www.ecobici.df.gob.mx/en/)

All systems can be categorized into the 4th generation according to the methodology described in the previous papers (Mátrai and Tóth, 2016a; b) of the authors. Except for the continental European ones, all other systems publish their usage statistics according to their open data policy and legal background.
The first radar chart (Fig. 1.) shows the weighted point in each main criteria from the user perspective and the second (Fig. 2.) from the operator perspective. This is the detailed results of the assessment.

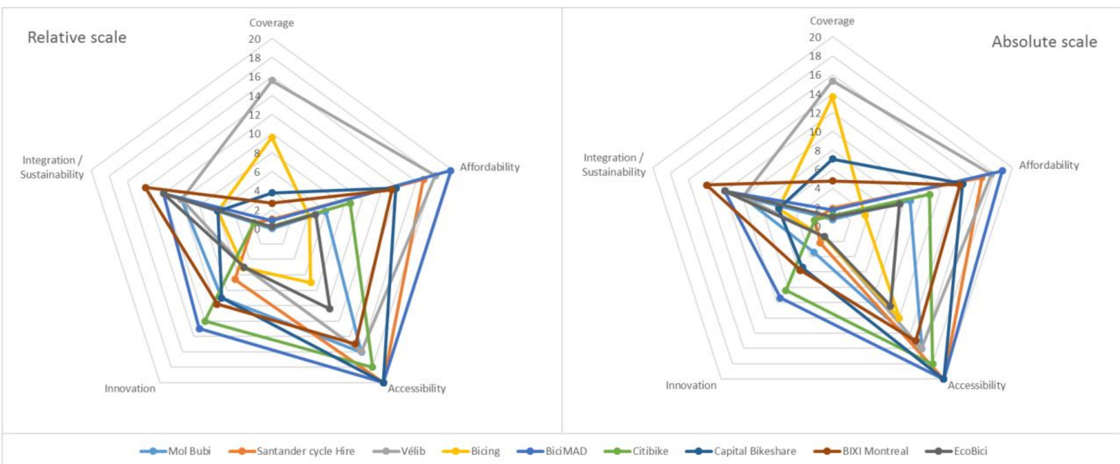


Fig. 1.
Radar chart of bike sharing system from user perspective using relative or absolute scale

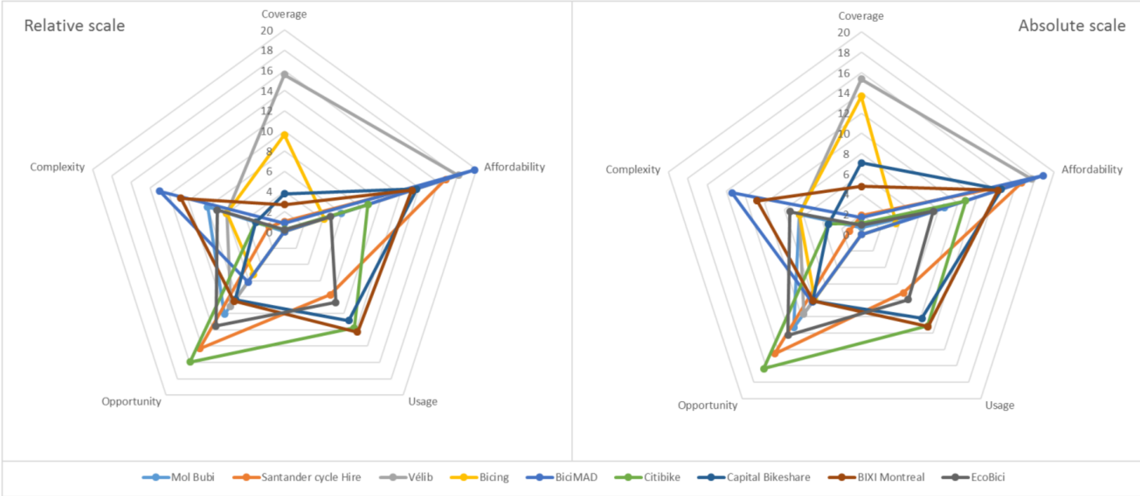


Fig. 2.
Radar chart of bike sharing system from operator perspective using relative or absolute scale

Fig. 3. shows the total points of each system visually and this is the sum of the previous charts. The vertical scale represents the total weighted points. 100 points can be reached in a relative scale if a system is the best in all sub-criteria, while in an absolute scale if a system reach the theoretical maximum in each sub-criteria.

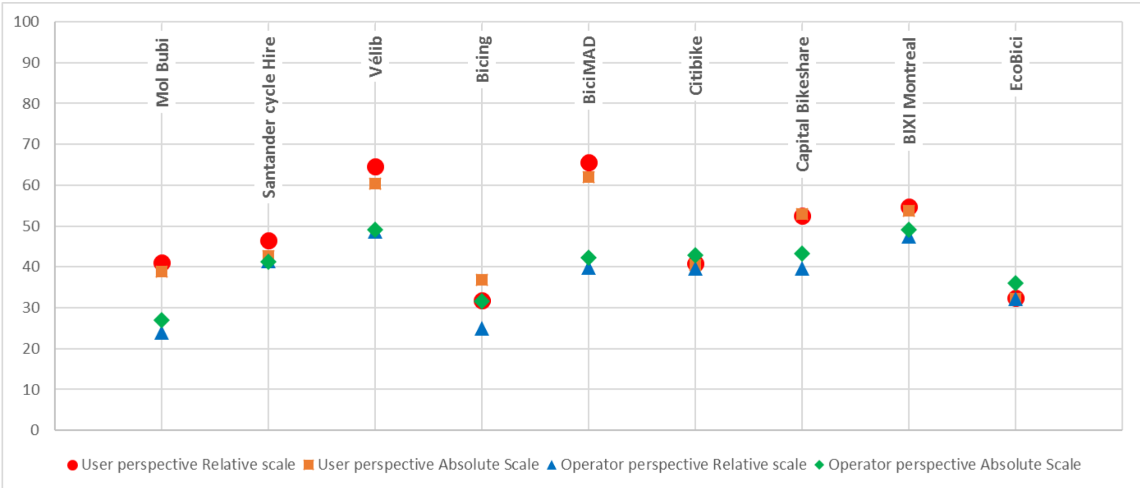


Fig. 3.
Comparison of system total points from different viewpoint and with different scale

Table 9 shows the ranking of the analysed systems from different perspectives. From user perspective the first five systems are the same in both scales, while in operator perspective this is only the case for the first two. Vélib and BIXI Montreal are in the top three in both perspectives.

Table 9
Ranking of the systems under investigation from different perspective and scale

User perspective		
#	Relative scale	Absolute scale
1	BiciMAD	BiciMAD
2	Vélib	Vélib
3	BIXI Montreal	BIXI Montreal
4	Capital Bikeshare	Capital Bikeshare
5	Santander cycle Hire	Santander cycle Hire
6	Mol Bubi	Citibike
7	Citibike	Mol Bubi
8	EcoBici	Bicing
9	Bicing	EcoBici

Operator perspective		
#	Relative scale	Absolute scale
1	Vélib	Vélib
2	BIXI Montreal	BIXI Montreal
3	Santander cycle Hire	Capital Bikeshare
4	BiciMAD	Citibike
5	Capital Bikeshare	BiciMAD
6	Citibike	Santander cycle Hire
7	EcoBici	EcoBici
8	Bicing	Bicing
9	Mol Bubi	Mol Bubi

5. Conclusion

Large amount of data has been collected from several PBS systems (nearly 80 systems, i.e. around 10% of the already existing set of around 800 systems), from which 9 has been selected for the application of our methodology. During the selection process we considered geographical representation, city size, transport behaviour differences, innovativeness in order to draw an appropriate sample. A methodology has been developed taking into account the literature review. The methodology has been applied to the selected systems and some general conclusions have been drawn.

It can be stated that system performance usually differs depending on user and operator perspectives, although some systems got similar points (such as EcoBici, Santander cycle Hire, Citibike). Points from user perspective are usually higher or the same in the relative scale.

Comparing the relative and absolute scales, the best performing systems are the same, which can be the result of that the theoretical maximum values are usually close to the best system's value.

The best systems show diverse characteristics. They got high points in different main criteria, which means they have different advantages and shortcomings. In the same time, they have similar total scores. None of the systems got total score close to the maximum 100 points, which was one of the prerequisites of the methodology development. The main opportunities and shortcomings are easily identifiable.

It has to be mentioned that this methodology, as it is normally the case, has certain limitations. Sample size has strong influence on the results if the relative scale is used. In the same time, using the absolute scale can be misleading if the theoretical maximum value calculations are wrong.

The advantage of the presented methodology is that it does not contain any sub-criteria which require expert judgement, in other words all sub-criteria are defined in a quantitative way. The financial and economic impacts are not used in this method, since cost-benefit analysis is a more elaborated solution for this purpose that, on the other hand, requires significantly more information from the PBS system. Usage statistics represent a very small part of the evaluation, since the authors believe that this way the method is easier to apply for both existing and planned systems. Usage statistics tend to be too optimistic (Kelly et al., 2015; Mátrai, 2013).

As always, the work is far from being completed. We identified the following topics for future research:

- Extend the sample for all 80 systems in the database,
- Add new sub-criteria,
- Develop questionnaires for users and operators in order to collect data to define weights for sub-criteria,
- Apply sensitivity tests on the methodology.

All the above mentioned research ideas may add important finding for the fine tuning of the methodology.

References

Van Audenhove, F.-J.; Dauby, L.; Korniichuk, O. Pourbaix, J. 2014. *The Future of Urban Mobility 2.0*, UITP, Brussels, Belgium.

Brown, V.; Diomedi, B.Z.; Moodie, M.; Veerman, J.L.; Carter, R.2016. A systematic review of economic analyses of active transport interventions that include physical activity benefits, *Transport Policy*, 45:190-208.

Buzási, A.; Csete, M. 2015. Sustainability Indicators in Assessing Urban Transport Systems. *Periodica Polytechnica Transportation Engineering*, 43(3): 138-145.

ECMT, 2004. Assessment and Decision Making for Sustainable Transport. Available from Internet: <http://www.oecd-ilibrary.org>.

Esztergár-Kiss, D.; Csiszár, C. 2016. Multicriteria Analysis of Hungarian Journey Planners, *Periodica Polytechnica Transportation Engineering*, 44(2): 97-104.

European Commission, 2011. Roadmap to a Single European Transport Area–Towards a competitive and resource efficient transport system. [online] Office for Official Publications of the European Commission. Available from Internet: <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Roadmap+to+a+Single+European+Transport+Area+?+Towards+a+competitive+and+resource+efficient+transport+system#0>.

Fishman, E. 2016. Bikeshare: A Review of Recent Literature. *Transport Reviews*, Available from Internet: <http://dx.doi.org/10.1080/01441647.2015.1033036>.

Fishman, E.; Washington, S.; Haworth, N. 2013. Bike Share: A Synthesis of the Literature. *Transport Reviews*, 33(2): 148-165.

Gyarmati, J.2003. *Többszempontos döntéselmélet alkalmazása a haditechnikai eszközök összehasonlításában*. Zrínyi Miklós Nemzetvédelmi Egyetem.

Kelly, C.; Laird, J.; Costantini, S.; Richards, P.; Carbajo, J.; Nellthorp, J. 2015. Ex post appraisal: What lessons can be learnt from EU cohesion funded transport projects?, *Transport Policy*, (37): 83-91.

Kindler, J.; Papp, O. 1975. *Komplex rendszerek egyes összemérési módszerei. A KIPA-eljárás módszertana és alkalmazástechnikája*, Budapesti Műszaki Egyetem Továbbképző Intézete, Budapest, Hungary.

Kindler, J.; Papp, O. 1977. *Komplex rendszerek vizsgálata. Összemérési módszerek*, Műszaki Könyvkiadó, Budapest, Hungary.

Koska, T.; Rudolph, F.; Schreck, B.; Vesper, A.; Halmos, T.; Mátrai, T.; Pawłowska, A.; Oskarbski, J.; Swennen, B.; Szabo, N.; Cavanagh, G.; Lepoudre, F., Millard, K., Wedderburn, M., Müller, M.; Knor, D. 2016. *The Role of Walking and Cycling in Reducing Congestion: A Portfolio of Measures* , Brussels, Belgium.

Kukadapwar, S.; Parbat, D. 2016. Estimation of optimal path on urban road networks using AHP algorithm, *International Journal for Traffic and Transport Engineering*, 6(1): 13-24.

Magyar, I.; Monigl, J.; Mándoki, P.; Kövesné Gilicze, É.; Holló, P.; Köves, G. 2000. *Városi és térségi közlekedés*, Magyarorsz ed. MTA, Budapest, Hungary.

Mándoki, P. 2005. *Személyközlekedési rendszerek értékelési lehetőségei a városi és térségi közlekedésben*, Budapesti Műszaki és Gazdaságtudományi Egyetem, Budapest, Hungary.

Mátrai, T. 2013. Cost benefit analysis and ex-post evaluation for railway upgrade projects, *Periodica Polytechnica Transportation Engineering*, 41(1): 33-38.

Mátrai, T.; Tóth, J. 2016a. Comparative Assessment of Public Bike Sharing Systems, *Transportation Research Procedia*, 14: 2344-2351.

Mátrai, T.; Tóth, J. 2016b. Közösségi kerékpárkölcsönző rendszerek értékelő elemzéséhez használható módszertan bemutatása. In: G.B. Dr Horváth Balázs, Horváth Gábor, ed., *Közlekedéstudományi Konferencia*. Győr: Széchenyi István Egyetem, 342-349.

Oliveira, R.C. 2010. *Introduction to Multicriteria Decision Analysis*, *Risk and Decision Making*, Lisbon, Portugal.

Rapcsák, T. 2007. *Többszempontú döntési problémák*. Available from Internet: <http://www.oplab.sztaki.hu>.

Saaty, T.L. 2008. Decision making with the analytic hierarchy process, *International Journal of Services Sciences*, 1(1): 83-98.

Tóth, J.; Mátrai, T. 2015. Újszerű , nem motorizált közlekedési megoldások. In *Proceedings of the Közlekedéstudományi Konferencia*.

CHILD-FRIENDLY MOBILITY - A GUIDELINE PUBLISHED BY THE AUSTRIAN RESEARCH ASSOCIATION FOR ROADS, RAILWAYS AND TRANSPORT (FSV)

Helmut Lemmerer[1], Thomas Macoun[2], Manuela Winder[3]
[1,2,3] Research Center of Transport Planning and Traffic Engineering - Vienna University of Technology, Vienna, Austria

Abstract: The guideline “Child-friendly Mobility” aims at designing public space in a child-friendly manner. It is effective for both urban and rural settlements and refers to the daily mobility of children aged between zero to fourteen. Children have needs and skills different from adults and their special needs should be taken into account. This will lead to a paradigm change in the transport planning process: it has to deal not only with the engineering of the transport space, but also the design of the living space for children. Participation of children themselves will play an important role in this new traffic planning approach.

Keywords: child-friendly mobility, transport planning, traffic safety, participation.

1. Introduction

In the recent decades, living and development conditions for children have largely changed. The increase of road traffic and its consequence led to a rise of risks from road traffic, air and noise pollution, lack of public space and leading to less physical activities of children, which affect the healthy child development at each stage of the childhood. Transport planners have to consider the requirements of all road users: creating a child-friendly environment poses new challenges for transport planners. This guideline serves to the child-friendly design of public space and is applicable for both urban and rural settlements. It refers to the daily mobility of children between zero and fourteen year-old. The guideline considers the entire world of experience and mobility of children. A number of international and national reports, conventions and action plans claim the design of an environment suitable for children, e.g.: children’s environment and health action plan for Europe (CEHAPE) (WHO, 2004), protecting children’s health in a changing environment (WHO, 2010), convention on the rights of the child (CRC) (UN, 1989), Austrian children's health and environment action plan (BMLFUW & BMGFJ, 2007), Austrian implementation report on healthy environments for children (BMLFUW & BMG, 2010), Austrian children and youth health strategy (BMG, 2012) and the Austrian action plan on physical activity (BMLVS & BMG, 2013).

2. Special needs of children

Independent and safe mobility is an important prerequisite for the healthy physical, mental and psychological development of children. The public space has to become more attractive for children. Accordingly, the design of public spaces has to be aimed to ensure safe road use and with the fact that children can move and play on their own without parental control.

The development of certain abilities of children differs greatly between age groups and individuals. Thus, children are a very heterogeneous group and must not be regarded as small adults since they differ in their thinking, perceiving and acting.

An appropriate transport planning action regarding children's requirements considers the developmental conditions for the participating children. Children's danger awareness is gradually developed based on their own experiences, e.g. watching accidents and explanatory notes of caregivers. By the age of about twelve children are able to anticipate risks and to take preventive actions. In addition, their estimation of distance, direction, and speed and their ability to empathize with other road users are learned step by step. Their field of view is smaller than adults by about a third and is not fully developed until the age of twelve. Thus, children's perception of lateral approaching danger is limited. They need more time to classify their visual and acoustic experience and they are more focused towards individual aspects than the overall impression of a situation.

2.1. Different age groups have different demands of the public space

Early childhood: Up to 3 years
The toddler age is a time of experimentation and experiencing. The child is interested in everything that comes from the outside world. Principal residence of the child is the living area or external sites e.g. playschool. In addition to walking, children start to move with tricycles, sit in the bike trailer or child seat in the car or use public transport accompanied by adults. The guidelines mainly refer to this age group by the needs of parents and caregivers.

[1] Corresponding author: helmut.lemmerer@tuwien.ac.at

Pre-schoolers: 4 to 5 years
The ability to move independently improves. New motion sequences are learned e.g. riding a bike. First cognitive, social and emotional skills are developed. Parents accompany the children in their trips and attendants stay within sight. They mainly play at specially intended places e.g. playgrounds, in yards or gardens.
Children of primary school age: 6 to 10 years
The desire for more open space increases. The children are interested in everything, to get active themselves and they are very eager for knowledge. Unaccompanied, children cover more and more trips (school, residential area). After passing the cycling proficiency test by the age of 10 years, they have the license to bike unaccompanied on the roadside in Austria.
Children in adolescence: 11 to 14 years
The radius of action of the young people increases and expands beyond the close to home area. With increasing age, adolescents take over spaces in the entire local area. At the same time, they stay in delimited areas in order to retreat. They prefer to walk, to cycle or to use public transport independently.
The possibility of independent mobility depends on the mobility network sector and the parental control.
Different mobility patterns by gender
In addition to the age, the usage of public space differs by gender. Research shows that boys have larger action areas than girls and they cover longer distances on foot or by bike. In general, boys have more accidents and they take over open space by active games. Girls are more interested in social games less aimed at competition. Particularly girls require safe refuges.

3. Considering needs of children as a prerequisite for a child-friendly transport planning

3.1. Independent mobility and child-friendly areas of activity

As soon as children have the opportunity to cover their daily trips by foot or bicycle, they often experience that the usage of their areas of activity is largely limited due to the risks of road traffic. However, this trend leads to a further increase of road traffic (e.g. parent taxis) and to an additional endangering of children who cover their trips by active modes.

3.2. Traffic safety

A large percentage of accidents involving children do not occur on routes to school as these are protected by crossing guards or traffic police. The large amount of road traffic and its high speed leads to stress in children and parents. As a result, parents prohibit unaccompanied stay and playing outdoors and/or drive children by car to various events and locations. Through that, children result in a lack of important experiences that strengthen their self-responsibility and self-confidence. All these skills are important mandatory requirements of an accident-free mobility. In addition, a high level of car availability results in the continuing decline of road skills of the children since they hardly learn to get around unaccompanied and thereby to correctly assess the road risks. Inexperienced and motoric untrained children have a higher injury risk than children with developed motor skills.

3.3. Participation

Present planning decisions affect the social, economic and ecological future of the children in the next decades. Participation is the involvement of children in decision-making processes of which they are affected, either directly or indirectly. Children should have the opportunity to discuss and to co-design. This is because at the age of four to six years, children can argue their view if the discussion is related to their direct neighborhood. By the age of seven children are able to get an overview of their immediate area of life and to take deliberative decisions. Children can be involved in almost all design tasks, ranging from the development of urban and rural transport concepts, up to public space design as well as the design of bus stops. It matters that the planning subject is as realistic and specific as possible with a direct relationship to their world of experience.

3.4. Planning actions

In addition, street design has to consider the needs of children. The overall planning goal is to achieve an advanced livability for children in public spaces and in urban areas. The quality of life depends on the use, density and zoning map and on the available free space. Following an overall consideration of the settlement area, it is thus possible to promote the respective means of transport according to their importance for children. In any case, high priority is given to traffic on foot, cycle traffic and public transport instead of the private motor vehicle.

3.5. Network Planning and spatial network

The entirety of all streets and places form a spatial network. The development of a general scheme and the assessment of a street require an overall design concept. Consistent with this approach further planning is supposed to be carried out. Where there is no overall design concept a current situation analysis is required. The spatial network has to consider the characteristics and the optimum applications of the various means of transport. Main street axes related to motor vehicle transport are possible. In addition, a stronger networking and mixing of the road space usage is essential for the purpose of street design beyond pedestrian zones.

3.6. Consideration of action spaces of children in planning process

Barriers such as heavy trafficked roads or tram/railway lines result in the remoteness of activities (separation effect, fragmentation). Due to barriers, the distance to school gets longer, shops and residences of friends can only be reached accompanied by adults (Fig. 1.).

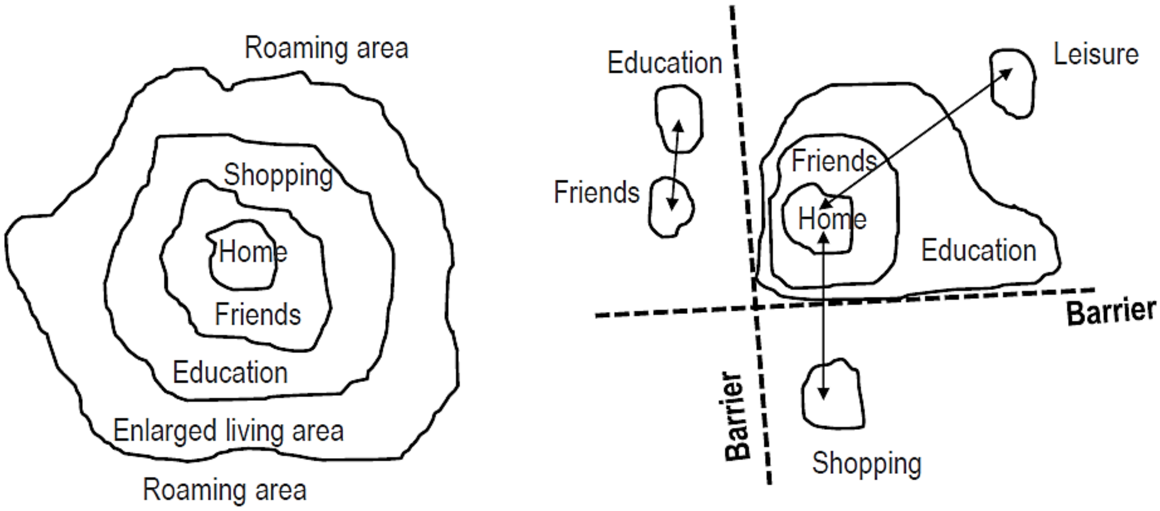


Fig. 1.
Model of occupation of the living area in concentric circles
Source: Busch (1995), own figure

Action spaces should be located in the immediate living area and not separated by e.g. risky road spaces. If necessary, the crossing of the road network has to be designed in a secure child-friendly manner. Action spaces of different age groups have to be considered in the planning action by providing respective extended zones (e.g. seven-year-old children are in need of an action space of at least 0.7 km²). Action spaces of children increase rapidly by age and achieve 3 km2 and more for ten year olds. Current traffic related measures are limited to traffic-calmed zones in living areas. A child-friendly planning approach however has to integrate urban functions such as education, leisure, green areas and shopping destinations. Therefore, indicators such as spatial density, location and accessibility, centralization and urbanity have to be examined.

4. Facilities of public space as a living and mobility space

The qualification and quantification of children's demands on the street space are the basis of the planning process. The demand derives from the needs of the adolescents. Little children up to primary school age require a secure routing in the course of their trip chain around the playground or the shopping area. The public space is supposed to be planned diverse in order to encourage children to establish a creative, self-directed utilization.

- Playground design by spacious and attractive playing areas,
- Green vegetation on public spaces (trees, hedges, shrubs, etc.),
- Spatially associated playing areas through safe pathways (attractive for both pedestrian and bicycle traffic),
- Easily accessible, safe crossing aids,
- Reduced motorized traffic in residential areas: setting up pedestrian areas, promotion of car-free neighborhoods (e.g. residential streets) to largely car-free residential areas and districts. Avoidance of truck traffic,
- Reduce speed of motorized traffic: Implementation of pedestrian areas. Widespread 30 km/h speed zones. Speed limit on major roads frequently used by children,
- Stronger focus of public transport on the needs of older children: Easy readable and comprehensible network, reduced ticket pricing, transport links to points of interests of children,
- Mobility management/mobility education: raise awareness for the needs and abilities of children (FGSV, 2012)

5. Conclusion

Independent and safe mobility is an important prerequisite for a healthy physical, mental and psychological development of children. Therefore, the design of public spaces has to consider both safe road use and the fact that children can move and play by themselves in the public space without parental control. Planning actions of road systems have be aligned to the needs of all road users particularly with regard to children. The implementation of a child-friendly environment raises new challenges for the traffic planning and management. In other words, a paradigm change must take place away from engineering transport space towards designing a child-friendly living space.

Acknowledgment

This paper is based on the guideline child-friendly mobility (RVS 03.04.13) prepared by the working committee urban traffic of Austrian research association for roads, railways and transport (FSV).

References

Bundesministerium für Gesundheit (BMG). 2012. *Kinder und Jugendgesundheitsstrategie*. Wien. [Federal Ministry of Health. *Austrian children and youth health strategy*].

Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW) & Bundesministerium für Gesundheit, Familie und Jugend (BMGFJ). 2007. *Kinder-Umwelt-Gesundheits-Aktionsplan für Österreich*. Wien. [Federal Ministry of Agriculture, Forestry, Environment and Water Management & Federal Ministry of Health. *Austrian children's health and environment action plan*].

Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW) & Bundesministerium für Gesundheit (BMG). 2010. *Aktionsplan für eine gesunde Umwelt für unsere Kinder. Umsetzungsbericht 2010*. Wien. [Federal Ministry of Agriculture, Forestry, Environment and Water Management & Federal Ministry of Health. *Austrian implementation report on healthy environments for children*].

Bundesministerium für Landesverteidigung und Sport (BMLVS) & Bundesministerium für Gesundheit (BMG). 2013. *Nationaler Aktionsplan Bewegung*. Wien. [Ministry of Defence and Sports & Federal Ministry of Health. *Austrian action plan on physical activity*].

Busch, K. 1995. *Kindgerechte Wohnumwelt, Grundsätze einer an den Bedürfnissen von Kindern orientierten Planung städtischer Wohnquartiere*. Carl von Ossietzky Universität Oldenburg. Oldenburg. [Busch, K. *Child-friendly living environment, policies towards the needs of children in the planning action of urban residential quarters*].

Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV). 2010. *FGSV 152 - Hinweise zur Integration der Belange von Kindern in die Verkehrsplanung*. FGSV Verlag. Köln. [German Road and Transportation Research Association. *Planning instructions on integrating the needs of children in transport planning actions*].

United Nations (UN). 1989. *Convention on the rights of the child (CRC)*. New York, U.S.A.

World Health Organization (WHO). 2004. Children’s environment and health action plan for Europe (CEHAPE). In *Fourth Ministerial Conference on Environment and Health. Budapest.*

World Health Organization (WHO). 2010. Protecting children’s health in a changing environment. In *Fifth Ministerial Conference on Environment and Health. “Protecting children’s health in a changing environment”.*

SESSION 10: ROAD TRAFFIC AND TRANSPORT RESEARCH - MODELING AND OPTIMIZATION

ESTIMATION OF CAR OWNERSHIP IN TURKEY USING ARTIFICIAL BEE COLONY ALGORITHM

Ersin Korkmaz[1], Erdem Doğan [2], Ali Payıdar Akgüngör [3]
[1,2,3] Civil Engineering Dept., Engineering Faculty, Kırıkkale University, Kırıkkale, Turkey

Abstract: This study proposes Artificial Bee Colony (ABC) models to estimate the number of cars in Turkey. In other words, car ownership is defined the number of cars per 1000 people. In the models development, population (P), per capita Gross Domestic Product (GDP) as dollars and fuel prices as Petrol, Diesel and Lpg were selected as model parameters. Two different ABC models were developed using the data covering from 2004 to 2015. According to fuel type, the coefficients of models were determined for each fuel type. Therefore, the sum of number of cars for each fuel type presented car ownership in Turkey. Developed models' results were statistically compared to observed values in terms of root mean square errors (RMSE), mean absolute percentage errors (MAPE) and coefficient of determination (R^2). The results of the ABC models showed that they were suitable to estimate the number of cars. To investigate the performance of ABC models for future estimations, a ten-year period from 2016 to 2025 was considered. Thus, future values of population were obtained from the projection of Turkish Statistical Institute (TSI) and the projections of other parameters, per capita GDP and fuel price, were executed according to current growth curve. The results obtained from future estimations reveal the suitability of ABC approach for determination of car ownership.

Keywords: car ownership, Artificial Bee Colony (ABC), Turkey.

1. Introduction

Especially, due to the rapid development of Turkey's economy in the last decade people's welfare and purchasing power are increasing. This increment affects car ownership as other socio-economic situations, and the number of cars is rising rapidly day by day. It is a fact that the rising of the number of cars has both positive and negative effects on people life. First of all, the private car is a component of modern life and is viewed as a symbol illustrating the people's status. Therefore, individuals in developed and developing countries desire to own their cars and benefit advantages of them. When individuals have their own cars, they are able to go wherever they want without the constraints of public transport timetables and the limitations of distance or time associated with walking and cycling. However, owing a car comes with some costs. Especially, while purchasing, taxes and maintenance costs of cars are directly related to individuals, other effects as increments in energy consumption, traffic congestions and air pollutions etc. and reductions in incomes of public transports are related to society and governments. In addition to these, car ownership data is used as a parameter by car manufacturers and oil companies to determine their strategies on products that are not yet on the market.

Due to the importance and effects of car ownership on society and economy, it has been intensely studied over many years by researchers. The first studies of this subject began in 1930s and have been developing since then. The very early research about the car ownership was started with (Wolff, 1938). A lot of researches, (Tanner, 1958, 1975; Mogridge, 1989 etc.) have studied on car ownership and have developed different forecasting models. Earlier models of car ownership were related to aggregate data and generally cross-sectional data, time series data etc. However, in recent decades researches have tended to centre on the development of disaggregate models. Because of developments in socio-economics conditions, individual's propensity and accessibility to own a vehicle have increased rapidly in especially developing countries. Pooled time-series data and panel data etc. were used by some researchers as (MVA Consultancy, 1996 and Hanly and Dargay, 2000). Jong *et al.* (2004) studied about car ownership and classified this subject in nine types. They are aggregate time series models, aggregate cohort models, aggregate car market models, heuristic simulation models, static disaggregate ownership models, indirect utility models of car ownership and car use, static disaggregate car-type choice models, panel models and pseudo-panel models and dynamic car transactions models. Nine types models were compared in terms of sixteen criteria, ranging from the treatment of supply, through level of aggregation and data requirements, to the treatment of scrappage. As a result, it was showed that the most preferred model type would vary from context to context. Whelan (2007) studied on modelling car ownership in Britain and he applied their models using a methodology known as prototypical sampling. After successfully validated models, they were used to forecast for future by taking into account changes to the socio-demographic characteristics of Britain. Clark (2009) attempted to predict the level of household car ownership as a function of the characteristics of the household and the individuals that make up the household. He showed that results of study were in line with those from previous research but performed a potential to predict the higher levels of household car ownership with greater accuracy than other similar studies. Some researchers from Turkey have studied about car ownership and they have applied different approaches to estimate car ownership. Ogut (2006) utilized Fuzzy Regression for modeling car ownership in Turkey. He determined the urbanization rate, average family size, gross national product per capita, average car cost, gasoline price and total length of roads as independent variables. He showed that using fuzzy method could be more practical than other methods. Codur and Tortum (2006) applied neural networks for modelling car ownership in Turkey. They selected four independent parameters which are GDP, petrol price, car price and road

[1] Corresponding author: ersin_korkmaz1@hotmail.com

lengths. The results of this study showed that Artificial Neural Network was more successful and reliable than other classical models in terms of nonlinear reflection ability.
Artificial Bee Colony (ABC) algorithm is one of these different approaches and the purpose of this study is to examine whether ABC is effective and useful to accurately estimate car ownership in Turkey. Two different ABC models were proposed based on population (P), per capita Gross Domestic Product (GDP) as dollars and fuel prices as Petrol, Diesel and Lpg. The performance of ABC models was evaluated by means of the root mean square error (RMSE), the mean percentage absolute error (MAPE) and the coefficient of determination (R^2) for both test and train data. Analysis results showed that all proposed car ownership models could be used for indicator of socio-economic studies and relationship between car ownership and development.

2. Details Experimental

2.1. Artificial Bee Colony Algorithm

Many of the real-world optimization problems are too complex and they may not be solved by developing mathematical formulas. When being tried to solve such a problem by using conventional methods, the solution may take too long time and results may not be located at desired solutions although it may take long time. In this case while searching for problem solution, intuitive (heuristic) methods have been developed and tried to reach the best results. Heuristic methods to solve a problem are known as the methods described to decide on the best solution from a variety of movements.
Artificial Bee Colony Algorithm is one of Artificial Intelligent and popular swarm based optimization algorithms. It is a stochastic global optimization method inspired by the foraging behavior of a honey bee swarm. Karaboga (2005) introduced firstly this algorithm in 2005 and applied in several fields to solve different problems up to date. In other words, ABC is an optimization algorithm created by following the example of their unique intelligent behavior of bees and by inspiring the method which bees use to search foods.
There are task-sharing in a bee colony collecting honey in their natural habitat. One of the most important things to ensure the continuation of the life of the bee colonies are foraging. There are some important factors in this process as the resources collected in the hive and feed sources can be found in the environment so on. The search process starting together with being removed hive by bees, it will initially continue with arbitrary food research. As a result of the reduction in the amount of food in found source, bees begin to forage or turn to other sources according to information received from other bees. That the information of found sources are transmitted to each other and sources as pollen and water so on. are brought to hive by bees are the activities carried out in the process.
As the minimal model of foraging behavior of honey bees, the colony of artificial bees in ABC are divided into three groups. They are employed bees associated with specific food sources, onlooker bees watching the dance of employed bees within the hive to choose a food source and scout bees searching for food sources randomly. At the beginning of algorithm, the food sources are investigated by scout bees and after that, it begins to be collected the nectar from these the sources. Thus, both found sources are used and information of sources are shared to onlooker by bees returning to employed from scout. While occurring convergence to point of solution with the move of onlooker bees to rich researches, new solution points are investigated by scout bees returning from employed bees in depleted sources. This situation continues in the cycle process until the optimal point is found. Food sources in algorithm refers to possible solutions of problems being tried to be optimized. The amount of nectar of a source refers to the quality value of the solution expressed by welding. Thus, the process of searching for good food sources can be considered as the process of finding the optimal solution.
Algorithm operation is carried out in four basic steps. They are as below:

- Determining of the initial values of sources.

Properly functioning of algorithm is related to the creation of the initial source correctly. Randomly determining the sources corresponding resolutions which involve all search space is the main concern. Initial resources are randomly generated in the lower and upper limits of each parameter. Mathematical expression of this step;

$$ {}_{i}^{0}x_j = {}^{min}x_j + rand(0,1)\left({}^{max}x_j - {}^{min}x_j\right) \tag{1} $$

where ${}_{i}^{0}x_j$ is created source, j = 1, …D and i = 1, …SN. D is the number of variables and SN is determined number of sources. ${}^{max}x_j \ ve \ {}^{min}x_j$ refer to lower and upper limits of each parameter.

- Direction of employed bees to sources.

One of the assumptions of this algorithm is that the number the number of employed bees is the same as the number of the food sources. There are seeking of new sources in neighborhood of first sources which employed bees have directed. Mathematical expression of neighborliness research;

$$ v_{ij} = x_{ij} + \emptyset_{ij}\left(x_{ij} - x_{kj}\right) \tag{2} $$

where x_{ij} is existing food source, v_{ij} is new resources sought in the neighborhood of the available resource and $\emptyset_{ij}$ is a random number varying between -1 and 1. There are limits for v_{ij} and in case of violation of these limits it is postponed to the limit again. Limit expression of v_{ij};

$$v_{ij} = \begin{cases} x_j^{min}, v_{ij} < x_j^{min} \\ v_{ij}, x_j^{min} \leq v_{ij} \leq x_j^{max} \\ x_j^{max}, v_{ij} > x_j^{max} \end{cases} \tag{3}$$

- Calculating selecting probabilities of food sources for onlooker bees.

According to information provided by the employed bees, source that has the highest fitness value will be selected by onlooker bees. The expression of each source's fitness function;

$$p_i = \frac{fitness_i}{\sum_{j=1}^{SN} fitness_i}$$

(Error! No text of specified style in document.)

where $fitness_i$ is the fitness value of i. and p_i is probability of selection.

$$fitness_i = \begin{cases} 1/(1+f_i), f_i \geq 0 \\ 1 + abs\,(f_i), f_i < 0 \end{cases} \tag{5}$$

where f_i is cost value of v_{ij}.

- Giving the decision of exclusion of the use of existing resources.

If there are depleted sources, they are abandoned and replaced with a new solution by scout bees. Otherwise, stopping criterion is checked without using replacing.

2.2. Development of ABC models

To develop ABC models, necessary data were obtained from Turkish Statistical Institute (TSI, 2015). Two different mathematical models, namely linear and power forms, given in Eqs. [6-7] respectively, proposed to estimate car ownership in Turkey.

Linear Form;

$$Co = w_1 * x_1 + w_2 * x_2 + w_3 * x_3 + w_4 \tag{6}$$

Power Form;

$$Co = w_1 * x_1^{w_2} * x_2^{w_3} * x_3^{w_4} \tag{7}$$

in which x_1 is the number of population, x_2 is per capita Gross Domestic Product (GDP) as Dollars and x_3 is fuel prices as Petrol, Diesel and Lpg. W_i is the corresponding weighting factors.
The coefficients of the models given in Table 1 are obtained by using ABC.

Table 1
The coefficient of models

Linear			Power		
Petrol	**Diesel**	**LPG**	**Petrol**	**Diesel**	**LPG**
w1=-0,053	w1=0,302	w1=0,281	w1=9,96E+15	w1=3,21E-28	w1=1,74E-36
w2=-45,009	w2=-144,695	w2=36,160	w2=-1,172	w2=4,964	w2=5,155
w3=-196784	w3=67993,920	w3=146526,400	w3=-0,031	w3=-1,633	w3=0,380
w4=8353598	w4=-19428816,540	w4=-18489778,100	w4=-0,245	w4=2,108	w4=0,402

According to fuel type, the coefficients of models were determined for each fuel type. Therefore, the sum of number of cars for each fuel type presented car ownership in Turkey. Since car ownership is defined the number of cars per 1000 people, the sum of number of cars for each fuel type is calculated as the number of cars per 1000 people.

3. Results and Discussion

The performances of models were evaluated in terms of error criteria which are RMSE, MAPE and R^2 defined in Eqs. 8-10.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(D_{Observed} - D_{estimated})^2} \tag{8}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Co_{Observed} - Co_{estimated}}{Co_{Observed}}\right| * 100 \tag{9}$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}(Co_{Observed} - Co_{estimated})^2}{\sum_{i=1}^{n}(Co_{Observed} - Co_{mean})}\right] \tag{10}$$

The performances of models for each fuel type were separately evaluated in terms of error criteria. The comparison results are illustrated in Table 2**.** As seen from Table 2, linear model illustrated better performance than power model for each fuel type. Especially, there are significant differences in terms of RMSE, MAPE and R^2 in diesel type. Linear model performed considerable values in MAPE and R^2 for each fuel type. They are 1.00, 9.35 and 3.11 for MAPE and also 0.9849, 0.9833 and 0.9979 for R^2, respectively. Car ownership values for per 1000 people have been calculated according to proposed models and are showed their results in Fig 1. The performance of the linear model are better than that of other model when the relationship between model estimates and observed data has been investigated. Fig 2 graphically illustrated this relation. As understood from Fig. 2, observed values and estimated values of linear model are in agreement and R^2 of this relationship is 0.9849.

Table 2
The Statistic of Data for Comparison

	Linear			Power		
	Petrol	**Diesel**	**LPG**	**Petrol**	**Diesel**	**LPG**
RMSE	51 739	125 965	67 055	50 342	21 6664	195 608
MAPE	1.00	9.35	3.11	1.18	24.91	8.16
R^2	0.9849	0.9833	0.9979	0.9858	0.9514	0.9747

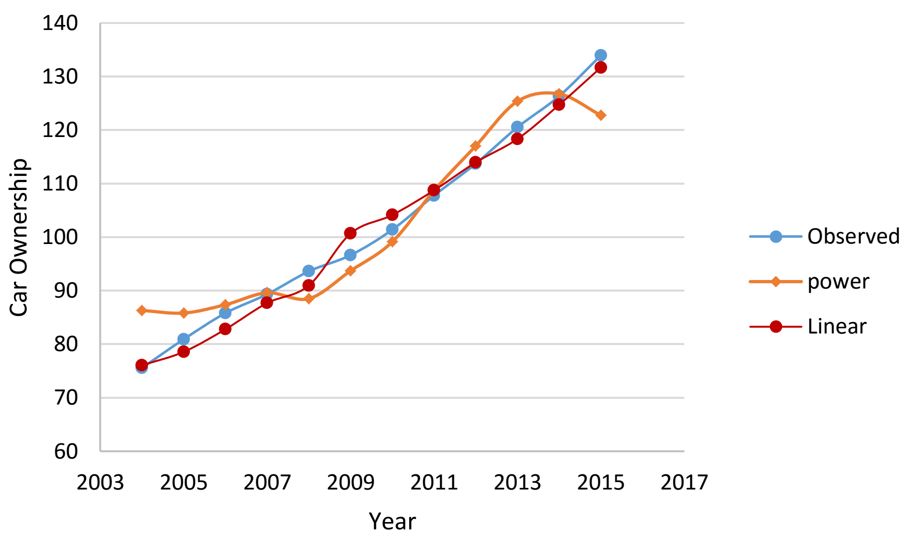


Fig. 1.
Car ownership distribution for years

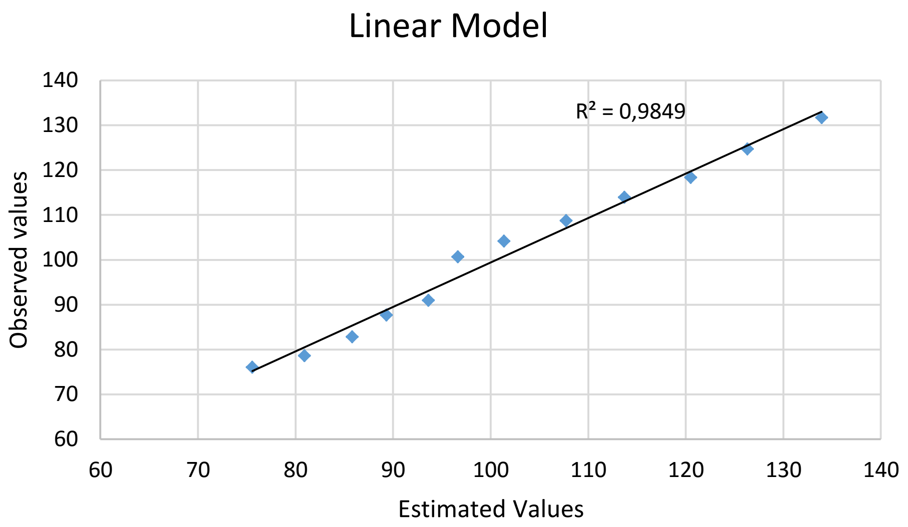


Fig. 2.
Relationship between observed and estimated values

4. Future estimates of car ownership for Turkey

Due to better performance of the linear model, it is selected to estimate the number of cars in the future. Thus, car ownership can be forecasted according to developed scenarios. In this section of the study, a scenario is considered to estimate car ownership until 2025. According to the projection of TSI, the population of the country will be around 85 million in 2025. The projections of other parameters, GDP and fuel price, were executed according to current growth curve. The average GDP and fuel price growth rate were taken as 5%. They will be around $14 941 for per capita GDP, TL 7.88 for petrol, TL 6.98 for diesel and TL 3.76 for LPG in 2025. The reader is referred to Table 3 for data on population and other parameters data used in this scenario. ABC Linear model estimates are tabulated in Table 4. The study results show that car ownership value steadily will increase in Turkey and will reach a value of 150.

Table 3
Population and other parameters' predictions

Year	**Future Estimates**				
	Population	**Per Capita GDP (Dollars)**	**Petrol (TL)**	**Diesel (TL)**	**LPG (TL)**
2016	78 965 645	9 631	4.66	4.13	2.23
2017	79 766 012	10 113	4.94	4.38	2.36
2018	80 551 266	10 619	5.24	4.64	2.50
2019	81 321 569	11 150	5.55	4.92	2.65
2020	82 076 788	11 707	5.89	5.22	2.81
2021	82 816 250	12 292	6.24	5.53	2.98
2022	83 540 076	12 907	6.62	5.86	3.16
2023	84 247 088	13 552	7.01	6.22	3.35
2024	84 936 010	14 230	7.43	6.59	3.55
2025	85 536 010	14 942	7.88	6.98	3.76

TL in Table 3 is Turkish Liras.

Table 4
Linear model car ownership estimates

Year	Car Ownership
2016	132
2017	135
2018	137
2019	140
2020	142
2021	144
2022	146
2023	148
2024	149
2025	150

5. Conclusion

This study presents an application of the ABC algorithm to estimate car ownership in Turkey for the next decade. ABC car ownership prediction models are developed by using a twelve-year historical data covering the years between 2004 and 2015. In the model development, two mathematical forms which are linear and power are determined. The population, per capita Gross Domestic Product as dollars and fuel prices as Petrol, Diesel and Lpg are considered as model parameters. A comparative study is performed among developed car ownership models and observed data. The all ABC models results are a good agreement with observed data. Especially, linear model is coherent with observed data. Therefore, linear model can be used for future estimates.
All developed models are statistically compared in terms of error criteria, such as RMSE, MAPE and R^2 for each fuel type. The results show that the performance of linear model is better than that of power in terms of RMSE and MAPE and R^2. Especially there are significant differences in terms of RMSE, MAPE and R^2 in diesel type.
In order to evaluate the future performance of the developed ABC linear model a scenario is considered. This scenario covers ten years' period from 2016 to 2025. According to the scenario, the population, per capita GDP, petrol, diesel and LPG price in Turkey will reach nearly 85 million and also $14 941, TL 7.88, TL 6.98 and TL 3.76 in 2025, respectively. The forecasting results show that car ownership value steadily will increase in Turkey and will reach a value of 150. The mean of this is an approximately 15% increase in car ownership between 2015 and 2025.
The performance of a model may increase with increasing the number of the model parameters and model forms. For further studies, other parameters which are effected on car ownership could be employed to improve the performance of the models.

Acknowledgements

The authors would like to thank Republic of Turkey General Directorate of Highways for providing traffic data.

References

Clark, S.D. 2009. The determinants of car ownership in England and Wales from anonymous 2001 census data, *Transport Research Part C: Emerging Technologies*, 17(5): 526-540.
Codur, M.Y.; Tortum, A. 2009. Modelling car ownership in Turkey using neural Networks. In *Proceedings of the Institution of Civil Engineers*, issue TR2, 97-106.
De Jong, G.C.; Fox, J.; Daly, A.; Pieters, E.; Smit, R. 2004. Comparison of car ownership model, *Transport Reviews*, 24(4): 379-408.
Hanly, M.; Dargay, J.M.; 2000. *Car Ownership in Great Britain – A Panel Data Analysis*. ESRC Transport Studies Unit University College, London.
Jones, S.R.; Tanner, J.C. 1979. *Car ownership and public transport, TRRL Report 464*, Transport and Road Research Laboratory, Crowthorne.
Karaboga, D. 2005. *An idea based on honey bee swarm for numerical optimization, Technical report TR06*, Erciyes University, Engineering Faculty, Computer Engineering Department.
Mogridge, M.J.H. 1989. The prediction of car ownership and use revisited, *Journal of Transport Economics and Policy* 23(1): 55-74.
MVA Consultancy, 1996. *Improved Car Ownership Models*, Report prepared for the Department of Transport.
Ogut, K.S. 2006. Modelling car ownership in Turkey using fuzzy regression, *Transportation Planning and Technology,* 29(3): 233-248.
Tanner, J.C. 1958. *An Analysis of Increases in Motor Vehicles in Great Britain, Research Note RN/1631*, Road

Research Laboratory, Harmondsworth.
Tanner, J.C. 1975. *Forecasts of Vehicles and Traffic in Great Britain: 1974 Revision, Transport and Road Research Laboratory Report LR 650*, Transport and Road Research Laboratory, Crowthorne.
Turkish Statistical Institute Road Traffic Accident Statistics, 1994-2015. Available from Internet: <www.tuik.gov.tr>.
Whelan, G. 2007. Modelling car ownership in great Britain, *Transportation Research Part A* 41: 205-219.
Wolff, P. 1938. The Demand for Passenger Cars in the United States, *Econometrica*, 113-129.

ASSESSING THE POSSIBILITIES OF REDUCING THE TRANSPORT COMPANY COSTS

Vieroslav Molnár[1], Katarína Pačutová[2]
[1,2] Technical University of Kosice, Kosice, Slovakia

Abstract: Article deals with economic evaluation and reduction of transport company costs. Costs reduction can be achieved by reducing fuel consumption in trucks and by choosing appropriate vehicle for packages transport of cargo to the company premises. Three types of vehicles are used for the research purpose. Fuel consumption and toll prices are considered essential indicators for choosing appropriate vehicle for delivering packages from 4 towns in East Slovakia to the specific destination.

Keywords: reducing, fuel consumption, costs, road freight transport.

1. Introduction

If the transport company wants to compete on the market it has to continuously face increased requirements and implement measures that optimize the company's operation which would lead to lower costs (Tomková et al., 2015). Costs of the company can influence profits of the transport company in the most significant way (Nedeliakova et al., 2016). The opportunity to succeed in the market full of competitors is given to that carrier who is able to work efficiently with available funds, thus efficiently operating their vehicle fleet (Ficzere et al., 2014). The customer can be given a lower cost while maintaining the quality of performed services and maintaining a reasonable profit for the transport by the carrier that is able to provide a sufficient number of performances with the vehicle fleet for the monitored period (Strohmandl, 2014). In road transport, small carriers often incorrectly determine the costs for transport and set the price for provided services accordingly (Fedorko and Čujan, 2014). Carriers often calculate incomplete costs or focus solely on price given for a realized unit of performance (Szendrő and Török, 2014). Thus set costs do not provide economically correct results by every transport (Poliak and Konečný, 2015). Fuel costs make up one of the highest cost items in goods transport. Since this is a variable cost, it is directly proportional to the realized performance and the higher the performance the higher the fuel consumption is (Cvengoš, 2013). Several authors are dedicated to possibilities of a reduction in consumption of trucks in terms of reducing the cost. Kment (Kment, 2010) deals with optimizing the fuel consumption of vehicles from the position of a vehicle producer, and further discusses the possibilities of the carrier. Jankovič (Jankovič, 2011) analyses in detail the historical development of fuel costs and national excise, road tolls and charges in the same relation. Gnap (Gnap, 2014) introduces a method of approach to the calculation of the impact of tolls on toll rates, focusing on carload shipments. Poliak (Poliak, 2010) introduces the issue of determining the share of tolls on the cost of transportation for unit cargo.
The aim of this paper is to highlight one of the options for reducing the cost of the company transport by reducing the fuel consumption in trucks and by choosing appropriate vehicle for packages transport of cargo to the company premises.

2. Material and Methods

For the research purposes, a company which is engaged in international road haulage was selected. The company owns 7 trucks with capacity up to 12 tons. The company´s customers are mostly in the industrial park in Kechnec and in towns Michalovce, Košice, and Prešov. Customers include smaller private companies and parcel delivery companies as Kühne Nagel, DHL, Schenker, Norbert Transport, etc. Fig.1 offers an overview of vehicles used in the company according to manufacturer mark, the amount of euro pallets, the volume of the load and capacity of the tank as well as EURO category. Three types of vehicles were used for the purpose of assessing the possibilities of reducing the transport company costs - namely Renault Master, DAF LF and Iveco Euro Cargo + render depicted in Fig. 1.

Fig. 1.
Renault Master Vehicles, DAF LF and Iveco Euro Cargo + render
Source: Authors

---

[1] Corresponding author: vieroslav.molnar@tuke.sk

Table 1
Company´s Car Park

Type of truck	Quantity of Euro pallets	Volume [m^3]	Tonnage [t]	Fuel tank volume [l]	EURO Category
Renault Master	8	20	1,5	110	EURO 6
Renault Master	8	20	1,5	110	EURO 6
Renault Master	8	20	1,5	110	EURO 5EEV
DAF LF	20	65	7	400	EURO 5EEV
DAF LF	20	65	7	400	EURO 5EEV
Iveco Euro Cargo + render	36	100	7	420	EURO 5EEV
Iveco Euro Cargo + render	36	100	7	420	EURO 5EEV

Source: Authors

Most shipments carried out in the company go to Germany, Luxembourg, Belgium, Netherlands, France, Italy, Slovenia, Czech Republic and Poland. Fig. 2 shows the market share and route map. Fig. 3 shows the cities of a collection.

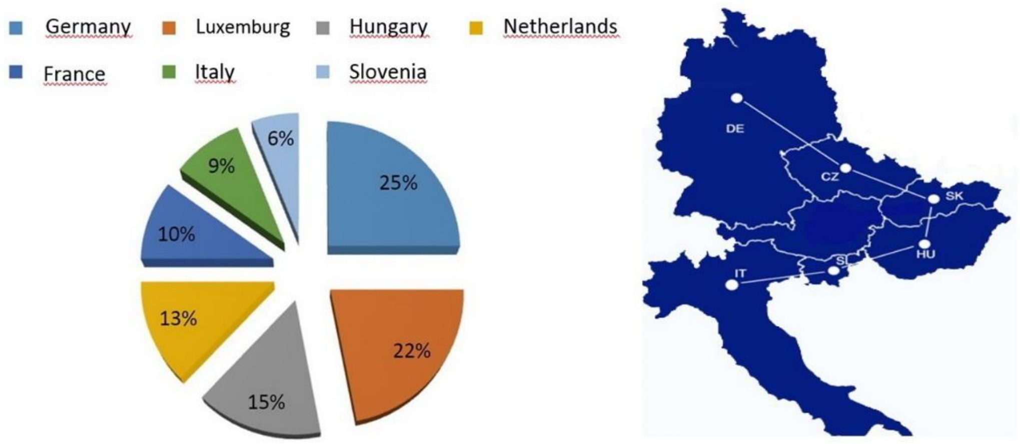


Fig. 2.
Market share and route map
Source: Authors

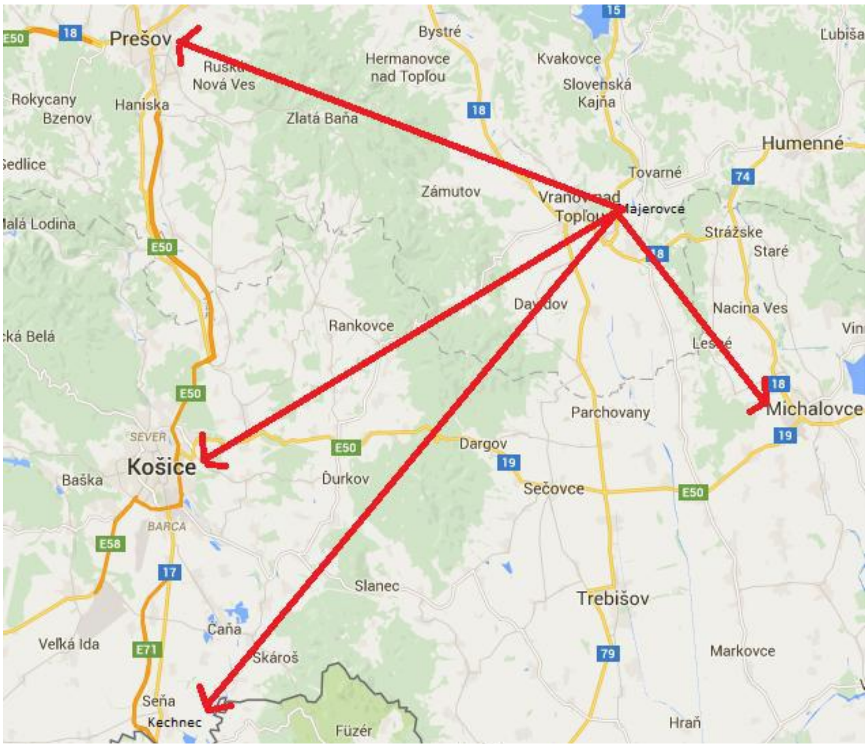


Fig. 3.
Cities of collection
Source: https://www.google.sk/maps

3. Reducing the Transport Company Cost

Costs reduction can be achieved by reduction of fuel consumption in trucks and by choosing appropriate vehicle for packages transport of cargo to the company premises.

3.1. Reduction of Fuel Consumption in Trucks

There are several ways for the company to reduce the fuel consumption in trucks. One way is to reduce the technical speed of the vehicle. The lower the speed the lower the fuel consumption in trucks. Technical speed was monitored mainly on motorways and expressways over the period of five years to determine the satisfactory and optimal technical speed that fulfills the required consumption.

3.2. Choosing Appropriate Vehicle for Packages Transport

The appropriate type of vehicle was chosen for collection of packages from Košice, industrial park Kechnec, from cities Prešov and Michalovce to company premises in Majerovce. Three vehicles were considered when choosing the appropriate type- Renault Master vehicle, DAF LF and Iveco Euro Cargo + render. The criteria for the right vehicle were the vehicle consumption and the price of toll fees. Examined indicators that were discussed during transport from Kosice, Kechnec, Michalovce and Prešov have similar values. Geographic location, the driver´s driving style, the distribution of goods in the vehicle area, the scale of packages or weight of packages affected the fuel consumption. The weight of packages depended on the city the package came from. Usually, the same packages were distributed and therefore the fuel consumption often reached a similar level.

4. Results and Discussion

4.1. Reduction of Fuel Consumption in Trucks

The achieved results over the period of five years divided into months for vehicles Renault Master DAF LF and Iveco Cargo + render are depicted in Fig. 4 - Fig. 6 and confirm the contemplated assumption about the reduction of consumption when reducing technical speed.

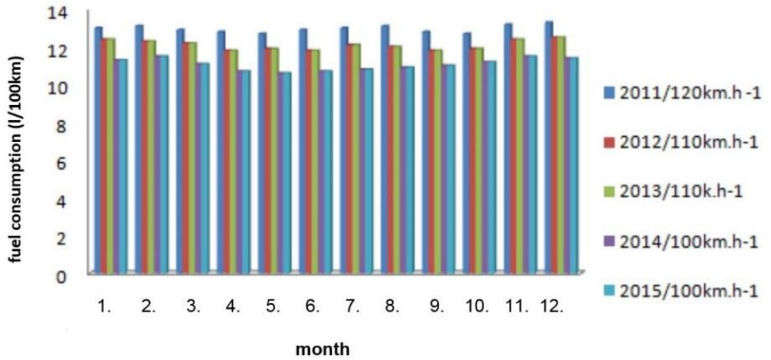


Fig. 4.
Fuel consumption 2011 – 2015 (Renault Master)
Source: Authors

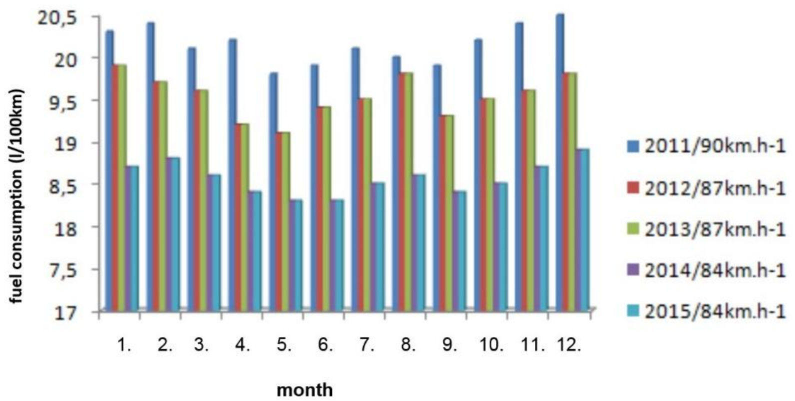


Fig. 5.
Fuel Consumption 2011 – 2015 (DAF LF)
Source: Authors

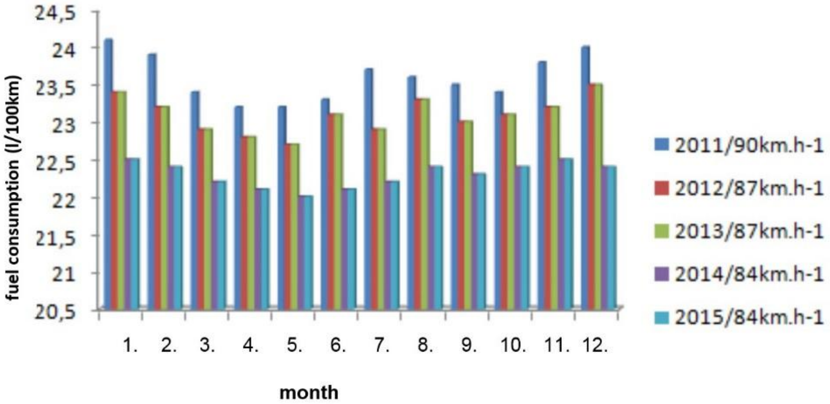


Fig. 6.
Fuel consumption 2011-2015 (Iveco Euro Cargo + render)
Source: Authors

In 2011 Renault Master vehicles were going on the motorways and expressways 120 km per hour. DAF LF with Iveco Euro Cargo + render vehicles were doing 90 km per hour. These speed values resulted in the highest fuel consumption values. In 2012 technical speed of vehicles was lowered in Renault Master to 110 km per hour. DAF LF and Iveco Euro Cargo + render lowered their speed to 87 km per hour. In 2013 the vehicles were going the same speed as in 2012. In 2014 the speed for Renault Master vehicles lowered to 100 km per hour. DAF LF with Iveco Euro Cargo + render vehicles lowered their speed to 84 km per hour. The same applies for the year 2015 when it was confirmed that this speed is satisfactory for driving on motorways and expressways. By lowering the technical speed less fuel was consumed which resulted in lower company costs.

4.2. Choosing Appropriate Vehicle for Packages Transport

Renault Master vehicle had the highest fuel consumption when transporting from Michalovce and the lowest when transporting from Prešov. Iveco Euro Cargo + render vehicle reached the highest consumption when transporting from Kechnec. DAF LF vehicle had the highest consumption when transporting from Košice. Fig. 7 depicts that difference in consumption while transporting packages was almost the same in all vehicles.

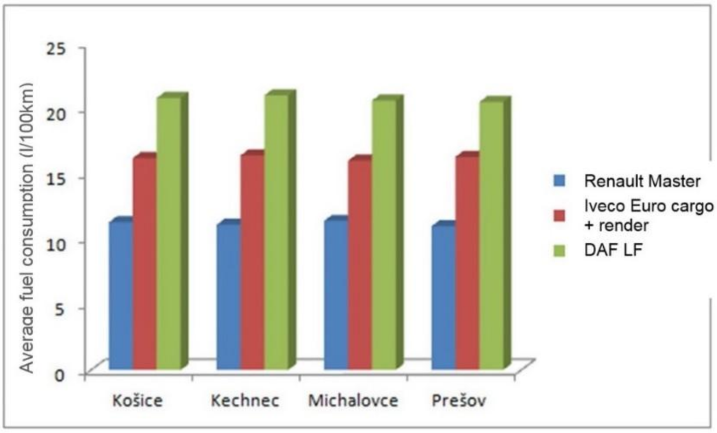


Fig. 7.
Average fuel consumption structure for packages transport
Source: Authors

The reason why toll fees were relatively similar despite the fact that the routes were of different lengths is that not all the sections of the routes were subjected to charges. Toll price was determined according to the emission classes of vehicles and the class. Solo vehicles belong to emission class EURO V, VI, and EEV class truck 3.5 tons - 12 tons. Toll charges do not apply to Renault Master and Iveco Euro Cargo + render. The highest price of tolls for DAF LF truck up to 12 tons was on a route from Kechnec mostly because the truck was driving through the toll sections. The lowest price of tolls was from the town Michalovce. For Renault Master vehicles and Iveco Cargo + render, there were no tolls on a two-way road from Kosice, Kechnec, Prešov, and Michalovce. The calculations showed that toll fees were at their highest on a route from Majerovce to Kechnec. The main reason for this was the highest price for the number of traveled sections as well as the highest number of package transports from an industrial park in Kechnec. For Renault Master and Iveco Euro Cargo + render vehicles, no toll fees applied. DAF LF vehicle paid 1.993,5 € in 2015. No toll fees applied to Renault Master and Iveco Euro Cargo + render on a route from Majerovce to Kosice, but DAF LF vehicle paid 727,04 €. 0 € were paid for Renault Master and Iveco Euro Cargo + render vehicles on a route from Majerovce to Presov, but DAF LF vehicle paid 512,04 €. The lowest prices were paid on a route from Majerovce to Michalovce. Renault Master and Iveco Euro Cargo + render vehicles paid 0 € and DAF LF vehicle only 32,3 €.

4.3. Final Evaluation

Fig. 8 depicts how 3,934.51 € will be saved in a year by exchanging Iveco Euro Cargo + render vehicle for Renault Master. The average price for fuel was 1,135 € per liter in 2015. 4,465.7 € were saved by choosing Renault Master vehicle for package transport in 2015. 7,402,91 liters of fuel would be saved if Renault Master vehicle transported the packages with lower volume instead of DAF LF vehicle. This would mean that a sum of 8,402.3 € is saved in 2015 taking into account an average price for fuel. A total sum of 3,936.6 € and 3,468.4 liters of fuel would be saved by exchanging Iveco Euro Cargo + render vehicle with DAF LF vehicle.

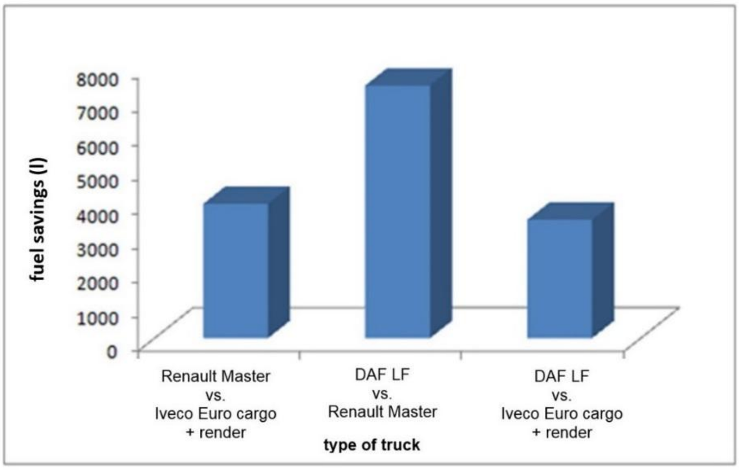


Fig. 8.
Fuel savings
Source: Authors

Fig. 9 depicts the toll price savings. Toll prices are not applicable to Renault Master vehicle. 3,264.9 € would be saved in 2015 by exchanging DAF LF with Iveco Euro Cargo + render vehicle. If the number of goods was smaller and a loading area of the Renault Master vehicle would be sufficient the company would save 3,264.9 € on toll fees *(Toll price savings).*

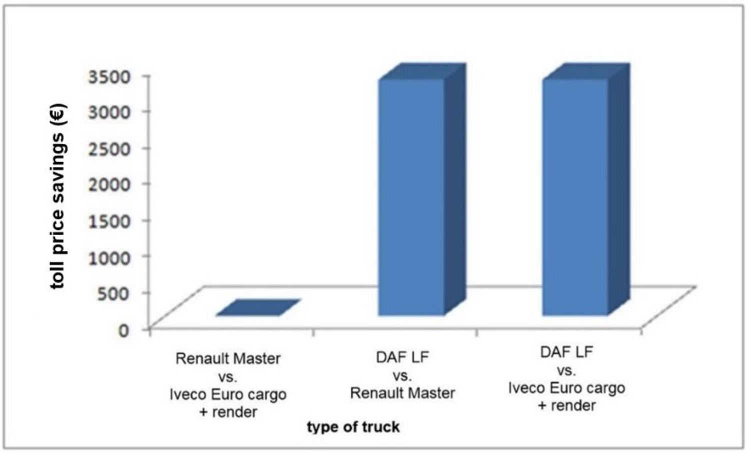


Fig. 9.
Toll price savings
Source: Authors

Fig.10 depicts total savings of fuel and toll fees. 4,465.7 € would be saved in 2015 if Iveco Euro Cargo + render is replaced by Renault Master. 7,201.6 € would be saved in 2015 if DAF LF is replaced by Iveco Euro Cargo + render. If it was possible to transport a required amount of goods by Renault Master instead of DAF LF it would save 11,667.2 € on fuel and toll fees.

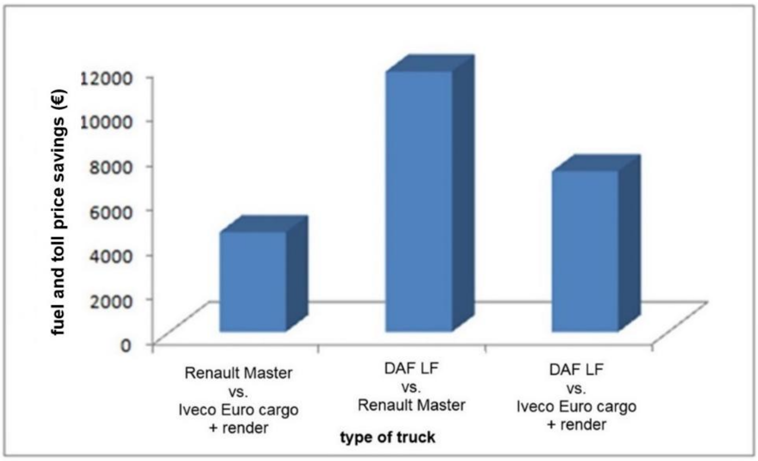


Fig. 10.
Fuel and toll price savings
Source: Authors

5. Conclusion

All the companies that do business want to achieve the best results in order to maximize their profits. The company costs belong to those items that influence the company's profit in the most significant way. Therefore companies use many methods to achieve the lowest costs. One way how to lower the costs is called cost reduction which can be achieved by reducing the fuel consumption in trucks and by choosing appropriate vehicle for packages transport of cargo to the company premises. The achieved results confirm that monitoring and optimizing the possibilities of lowering transport costs is important.

Acknowledgements

This work is a part of these Slovak projects VEGA 1/0258/14, VEGA 1/0063/16, KEGA 006STU-4/2015, KEGA 018TUKE-4/2016.

References

Cvengoš, S. 2013. Náklady a pohonné hmoty, *TOP Magazín O Motorizme, Doprave, Zasielateľstve a Logistike Transport a Logistika*, 13(4): 9-10.
Fedorko, G.; Čujan, Z. 2014. Optimization in modern business practice. In *Proceedings of the International Conference on Industrial Logistics, ICIL 2014*, 167-175.
Ficzere, P.; Ultmann, Z.; Török, Á. 2014. Time–space analysis of transport system using different mapping methods, *Transport*, 29(3): 278-284.
Gnap, J. 2014. Mýto a kalkulácia ceny v doprave 2014, Odborný Seminár Pre Zasielateľov a Dopravcov. Available from Internet: < http://www.logistickymonitor.sk/images/prispevky/seminar-2014-zbornik.pdf.>.
Jankovič, P. 2011. Náklady v doprave problém nás všetkých..., *Kilometer-Informačný Spravodajca Združenie Cestných Dopravcov*, 11(12): 14.
Kment, R. 2010. Hľadáme rezervy v spotrebe, *Truck & business*, 10(1): 64-66.
Nedeliakova, E.; Sekulova, J.; Nedeliak, I.; Abramović, B. 2016. Application of Raymond fisk model in research of service quality, *Communications*, 18(2): 11-14.
Poliak, M. 2010. Kusové zásielky a mýto, *Truck & business*, 4: 26-28.
Poliak, M.; Konečný, V. 2015. Analýza vybraných nákladov dopravcov cestnej nákladnej dopravy. Available from Internet: < http://www.logistickymonitor.sk/en/images/prispevky/analyza-nakladov-dopravcov.pdf.
Strohmandl, J. 2014. Use of simulation to reduction of faulty products, *UPB Scientific Bulletin, Series D: Mechanical Engineering*, 76(3): 223-230.
Szendrő, G.; Török, Á. 2014. Theoretical investigation of environmental development pathways in the road transport sector in the European Region, *Transport*, 29(1): 12-17.
Tomková, E.; Husáková, N.; Strohmandl, J. 2015. Possibilities of economic efficiency solution in road haulage. In *Proceedings of the Transport Means - 19th International Conference on Transport Means*, 694-697.

THE IMPACT OF VARIOUS ORGANISATIONAL MEASURES ON THE LOGISTICS COSTS OF COMPANIES IN THE AUTOMATIVE INDUSTRY

Sebastjan Škerlič[1], Robert Muha[2]
[1,2] University of Ljubljana, Faculty of Maritime Studies and Transportation, Pot pomorščakov 4, SI-6320 Portorož, Slovenia

Abstract: The use of systems for controlling logistics costs is not the only activity that guarantees lower logistics costs in companies. There are also various organisational measures within the company, such as the centralisation of logistics and establishing a system for encouraging innovation, which can have a significant impact on the effectiveness of cost management within the company's logistics department. To this end, a survey was conducted on a sample of 30 Slovenian companies that are suppliers to the international automotive industry. The goal of the study is to analyse the impact of the implementation of these measures on the level of logistics costs in the automotive companies. The results of the study are an important starting point in the development of modern methods for controlling logistics costs. They represent an important contribution to ensuring the development of the economics of transport, warehousing and other logistics costs in manufacturing companies operating in the automotive industry.

Keywords: logistics costs, centralisation of logistics, innovations, automotive industry.

1. Introduction

The small size of the Slovenian market drives companies in the Slovenian automotive industry to seek business opportunities outside local frameworks. Once they find themselves in an international environment, they face unrelenting competition in terms of providing high quality products and services. In addition, they are increasingly confronted with demands for a systematic reduction of costs. Up until now, companies have mitigated the effects of cost reductions by achieving greater productivity and better quality and with continuous product improvement. However, the fact is that many suppliers have reached the stage where significant cost reductions cannot be achieved by improving productivity and quality (Singh et al., 2005). Cost reduction in the supply chain is an even more sensitive issue, because it leads to poor-quality logistics services.

Logistics costs account for most of the costs in a company's supply chain. They also cover a significant share in the cost structure of the company as a whole. There are significant differences in the level of logistics costs between companies from different industries, despite several scientific studies indicating that their share in the total sales revenue of a company amounts to at least five percent. When defining logistics costs, it is important to consider the integrity of these costs as they occur in different business areas. The authors referenced in this paper (Stock and Lambert, 2001; Zeng and Rossetti, 2003; Christopher, 2005; Fugate et al., 2010; Engblom et al., 2012) classify logistics costs as a percentage of revenues from sales of goods and identify at least six individual cost components: transportation, warehousing, inventory management, administration, packaging and indirect logistics costs.

Therefore, in the highly competitive environment of the automotive industry, efficient logistics costs controlling plays an important role, because it ensures that the supply of all subjects that are part of the supply chain runs smoothly. Apart from the use of various logistics cost controlling systems, companies can make use of various organisational measures such as the centralisation of logistics and setting up a system to encourage innovation, in order to optimise the processes in the supply chain.

A centralised approach to organizing logistics means that companies have a separate department uniting all the logistics activities that were previously dealt with by different departments (e.g. sales, purchasing, manufacturing, etc.), under the same management. The commitment to the constant development of products, services and processes requires companies to focus on the process of encouraging innovation. Setting up a mechanism to encourage innovation company-wide can lead to the long-term creation of ideas and initiatives to control logistics costs.

The purpose of this study is to analyse the impact of the implementation of the centralisation of logistics operations and the establishment of a system aimed at encouraging innovation on the level of logistics costs. The results of the study represent an important contribution to ensuring the development of the economics of transport, warehousing and other logistics costs in manufacturing companies operating in the automotive industry.

In the second chapter, an overview of the international automotive industry and the processes currently taking place on the route between automotive manufacturers and suppliers is presented. The third chapter consists of a statistical analysis, followed by a discussion in the final chapter.

2. Participation in the international automotive industry

Over time, the automotive industry reached a level of development that sets an example for other industry sectors in terms of process management and strengthening relationships in the supply chain. Taking part in this industry has many advantages, but also entails certain responsibilities, as demands for the optimisation of business processes are passed from the end-customers down the supply chain. The importance of this industry lies largely in its connection to the domestic and international economy and its complex value chain. The automotive industry is one of the world's largest

[1] Corresponding author: sebastjan.skerlic@fpp.uni-lj.si

job creators, employing more than two million people, which accounts for approximately 5.5% of all jobs in EU-27 countries (ACEA, 2016).
The majority of new vehicles come from the assembly lines in sophisticated and highly structured processes. Manufacturing 60 million vehicles requires around 9 million employees, who are directly involved in the manufacture of vehicles and their parts. It is estimated that every job position provided directly by a particular car manufacturer (e.g. BMW, AUDI, FORD, TOYOTA and others) supports at least 5 indirect jobs in the community. From this perspective, the automotive industry contributes at least 50 million jobs worldwide, since manufacturing vehicles requires the use of various goods and services from different industrial sectors. Among the most important are steel, iron, aluminium, plastic, glass, carpets, textiles, computer chips, car tyres and other goods (OICA, 2016). Figure 1 shows the total sales of vehicles of the past ten years. Following a period marked by the international financial crisis in 2008 and 2009, which saw a decrease in sales, there was a 25% increase in 2015, compared to the period before the crisis. Thus, participation in the international automotive industry represents many business opportunities and challenges for Slovenian suppliers.

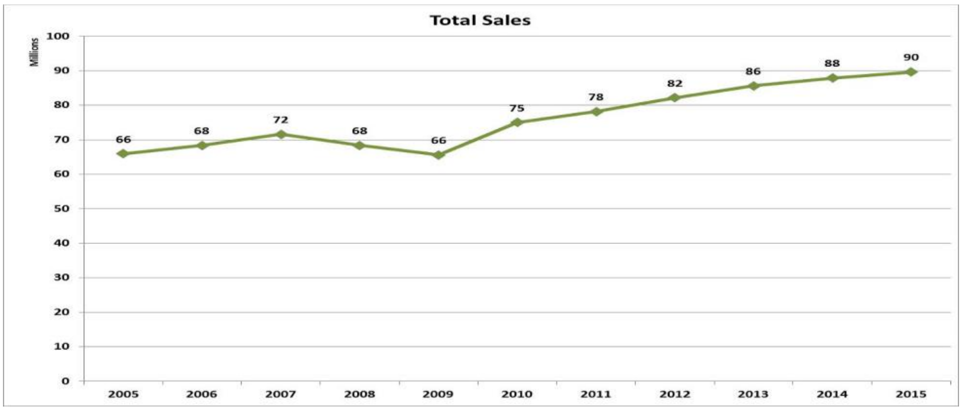


Fig. 1.
The number of vehicles sold from 2005 to 2015 in million EUR
Source: OICA, 2016

A look at the production of motor vehicles worldwide between 2000 and 2014 (Figure 2) reveals a marked increase in production in China. As early as in 2000, 4% of the total world motor vehicle production was concentrated in China, while in 2014, this share rose to 27%.

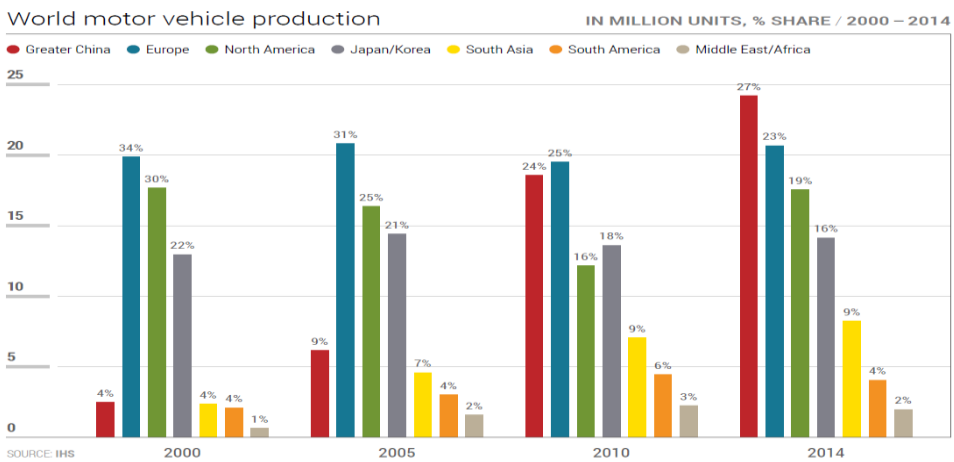


Fig. 2.
World motor vehicle production by country from 2000 to 2014
Source: ACEA, 2016

The global automotive sector is constantly evolving. Fierce competition pushes companies to excel in the various fronts, including cost, design, functionality, manufacturing and quality (Park and Simpson, 2005). In addition to expectations regarding quality management, first tier suppliers in the automotive industry in particular are subject to strategic requirements, which are indirectly related to implementing and strengthening the concept of lean manufacturing (Singh et al., 2005):

- continuous pressure to reduce costs,
- increasing innovation,

- achieving high production capacities,
- achieving ecological and environmental standards,
- achieving high safety standards,
- close proximity to production facilities,
- integrating a 3PL (Third Party Logistics Provider),
- greater integration in post-sales activities and
- effective computerisation of business processes.

The need for continuous cost reduction is seen as a competitive necessity worldwide (Womack et al., 1990). It is quite common for automotive manufacturers to demand that their suppliers reduce the costs of components by 2.5 to 5.0% annually. In most cases, this demand is non-negotiable, which means that suppliers are under extreme pressure to achieve an acceptable level of costs as demanded by the manufacturers. Thus far, suppliers have been succeeding at meeting this demand primarily by achieving greater productivity, better quality and continuously improving their products. Singh et al. (2005) indicate that many suppliers have reached the stage where significant cost reductions are no longer achievable by improving productivity and quality. This is confirmed by a study by Roland Berger (2014), as it points out possible friction in the relationship between automotive manufacturers and suppliers. Figure 3 shows the current and future efforts by automotive manufacturers (VW, BMW, Daimler, PSA and Renault-Nissan) to reduce costs and the effects on relationships with suppliers.

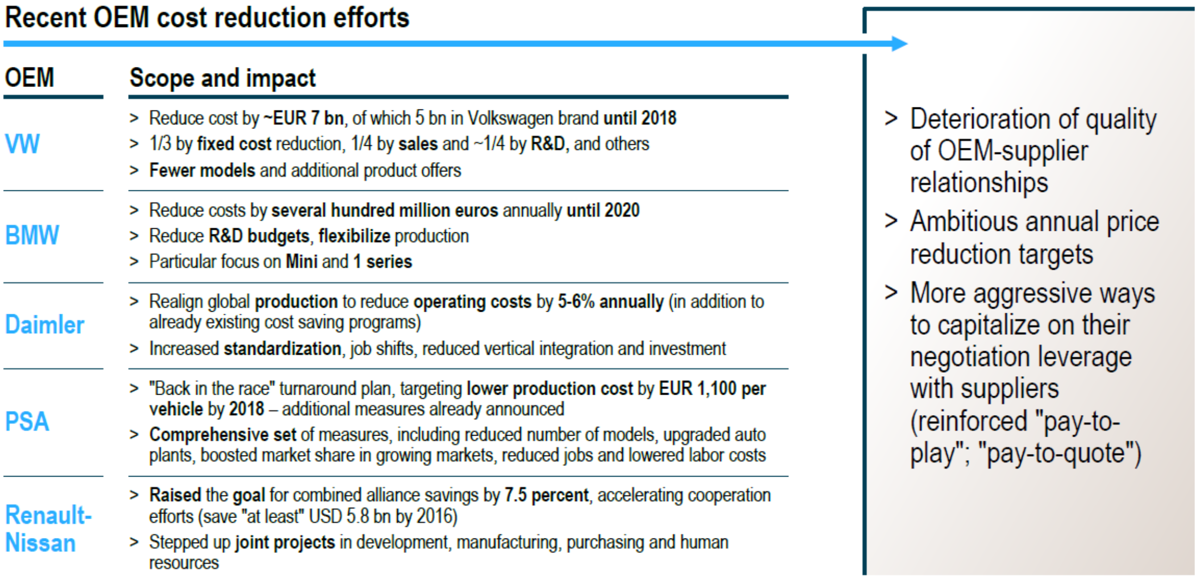


Fig. 3.
The demands for cost reduction by automotive manufacturers towards suppliers
Source: (Roland Berger, 2014)

When examining the cost structure of a vehicle, Figure 4 indicates that the cost of materials purchased is 53%. Ambitious annual targets of automotive manufacturers to reduce prices with suppliers derive from the above fact. Labour costs are surprisingly low, but if we take into account the personnel costs in the entire supply chain of a company (including on the suppliers' side), the entire value chain in the automotive industry reveals a different picture (Figure 5).

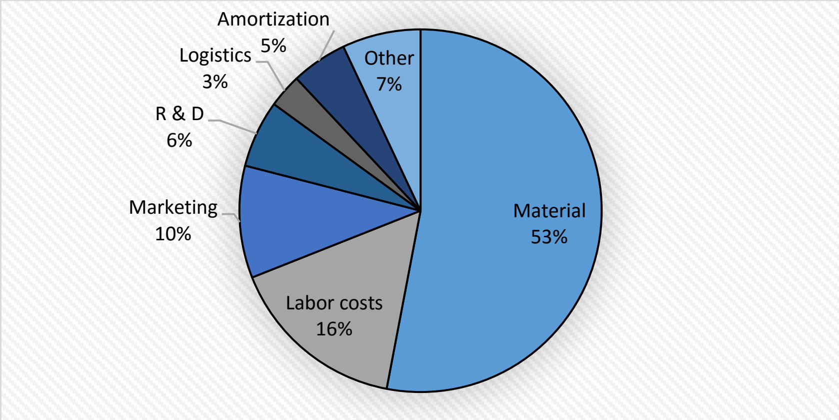


Fig. 4.
The cost structure of a vehicle
Source: Primc, 2011

In this case, labour costs amount to 70% of the entire value chain, while the costs of materials are reduced to 10%. Figure 5 also shows the potential savings that could be achieved, if automotive manufacturers were to reduce their vertical integration and thereby give a larger share to suppliers from countries where labour is cheaper (Primc, 2011).

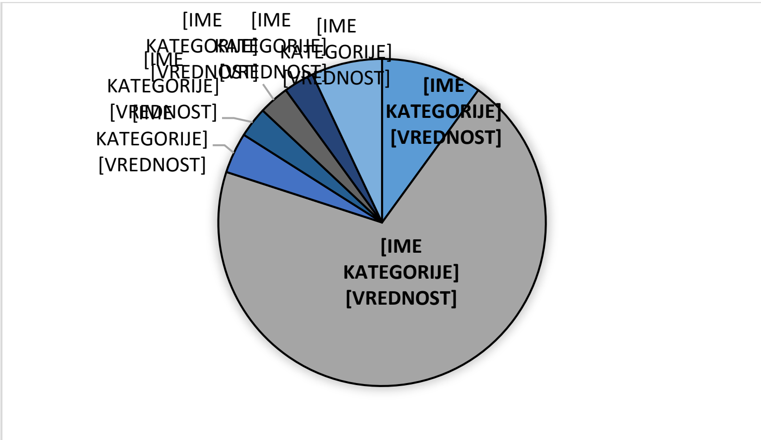


Fig. 5.
The cost structure of the entire value chain
Source: Primc, 2011

In light of the facts presented above, it becomes more clear why there has been an increase in the production of vehicles in countries with cheaper labour that also offer access to a cheaper base of local suppliers. It is precisely these facts that enable automotive manufacturers to have a more aggressive approach in exploiting their negotiating power towards suppliers, mainly in Europe.

3. Results

The survey was conducted on a sample of 30 Slovenian companies that are suppliers to the international automotive industry and lasted between February and May 2015. The share of logistic costs in company revenue was an ordinal variable measured on a four-point scale (1 = < 5%; 2 = 5– 9%; 3 = 10-20%; 4 = >20%). The centralisation of logistics services and innovation encouragement were dichotomous variables. The difference in logistic costs between categories of dichotomous variables was examined by Mann-Whitney U test. The level of statistical significance was set to α = 0.05 (one-tailed) when factors influencing lower logistic costs were examined as the direction of associations was presupposed. Statistical analysis was performed in IBM SPSS 22.0.
Table 1 shows the results of testing differences in logistic costs between categories of dichotomised variables such as centralisation of logistics and innovation encouragement. Companies encouraging innovation have statistically significantly (p = 0.023) lower logistic costs (Me = 1, i.e. < 5 %) than companies not encouraging innovation (Me = 3; i.e. 10-20%). Companies with centralised logistics seem to have similar logistic costs to those with decentralised logistics.

Table 1
Median value of the share of logistic costs by centralisation of logistics and innovation encouragement and results of Mann-Whitney U test

Factor in the company	n	Me	U	p
Centralization of logistics				
Yes	17	1.0	64.5	0.109
No	10	1.5		
Innovation encouragement				
Yes	23	1.0	30.0	**0.023**
No	5	3.0		

Note: * n = number of companies; Me = median value of logistic costs rate
(1 = < 5%; 2 = 5– 9%; 3 = 10-20%; 4 = >20%).

4. Discussion and conclusion

The analysis of the results shows that innovation has the greatest impact on the level of logistics costs. Companies that have implemented a system for encouraging innovation have lower logistics costs in comparison with companies that do not have such a system in place. As expected, innovations have the biggest influence on logistics costs, because of the specific nature of logistics operations that require seeking the best cost solutions in terms of streamlining transport, warehousing, operational and other logistics costs. The continuous development of information technology (advanced programs and decisions-making tools), work instruments (RFID, Barcode, etc.), means of transport (efficient and economical vehicles) and the logistics network (new road, rail, air, sea connections and distribution centres) enables a wide selection of innovative and modern logistics solutions, which can result in lower total logistics costs.
The results of the study represent an important contribution to ensuring effective systems for controlling logistics costs and a set of important guidelines for a better organisation of logistics systems in manufacturing companies operating in the automotive industry.

References

ACEA. 2016. The Automobile Industry Pocket Guide 2015/16. Available from Internet: <http://www.acea.be/press-releases/article/new-automobile-industry-pocket-guide-launched>.
Berger, R. 2014. Global Automotive Supplier Study. Available from Internet: <https://www.rolandberger.com/media/pdf/Roland_Berger_Global_Automotive_Supplier_Study_20141209.pdf>.
Christopher, M. 2005. Logistics and supply chain management: creating value-adding networks. Harlow; Financial Times; Prentice Hall: Pearson. 305 p.
Engblom, J.; Solakivi, T.; Toyli, J.; Ojala, L. 2012. Multiple-method analysis of logistics costs, *International Journal of Production Economics*, 137: 29-35.
Fugate, B.S.; Mentzer, J.T.; Stank, T.P. 2010. Logistics Performance: Efficiency, Effectiveness, and Differentiation, *Journal of Business Logistics*, 31(1): 43-62.
OICA. 2016. A Growth Industry. Available from Internet: <http://www.oica.net/category/economic-contributions/>.
Park, J.; Simpson, T.W. 2005. Development of a production cost estimation framework to support product family design, *International Journal of Production Research*, 43(4): 731-772.
Primc, R. 2011. Predvidevanje poslovnega okolja v avtomobilski dejavnosti:magistrsko delo, Ljubljana, 86 p.
Singh, P.J.; Smith, A.; Sohal, A.S. 2005. Strategic supply chain management issues in the automotive industry: an Australian perspective, *International Journal of Production Research*, 43(16): 3375-3399.
Womack, J.P.; Jones, D.T.; Roos, D. 1990. The Machine that Changed the World, Rawson Associates: New York.
Stock, J.R.; Lambert, D.M. 2001. Strategic logistics management, 4th ed., Boston [etc.] : McGraw-Hill: Irwin, 872 p.
Zeng, A.; Rossetti, C. 2003. Developing a Framework for Evaluating the Logistics Costs in Global Sourcing Processes, *International Journal of Physical Distribution & Logistics Management*, 33(9): 785-803.

OPTIMAL ROUTE DESIGN FOR SHARED PARA TRANSIT SERVICE IN PATNA, INDIA

Vijaya Bandyopadhyaya[1], Ranja Bandyopadhyaya[2]
[1] *Chandragupta Institute of Management, India*
[2] *National Institute of Technology, Patna, India*

Abstract: In most small cities in India, para transits form the basic mode of shared transport that people use for their daily commuting. These para transits include autos (motorized three wheelers) and taxis or cabs. These small transit systems usually carry about 5 to 6 passengers and ply on fixed short routes ranging from 3 to 8 kms. With increase in population and travel demand, there has been a huge increase in the number of para transit vehicles, particularly autos in recent years and optimal scheduling of para transit is essential. The current work suggests a dynamic framework for optimal scheduling of para-transit operations considering the randomness in arrival of passengers. It assumes a stochastic queuing model for scheduling of para transit operations such that the waiting times are minimized and the cost of operations is realized with an optimal level of profit.

Keywords: para transit, optimal scheduling, queuing.

1. Introduction

In most small cities in India, shared para-transits form the basic mode of transport for people for their daily commuting. These para-transits include shared autos (motorized three wheelers) and shared taxis or cabs. These small transit systems usually carry about 5 to 6 passengers and ply on fixed short routes ranging from 3 to 8 kms. They follow a fixed route of operation. With increase of population and travel demand, more number of these para-transit vehicles ply on the roads resulting in increased congestion in the links.

The para transit operations are demand based and do not follow a definite schedule of start and stoppages. The scheduling of para transit is a complex problem involving minimization of user waiting time, minimization of user travel time, deciding the optimal stopping locations in the network, and maximization of profit for the vehicle drivers.

Very few existing works focus on routing and scheduling of para transit operations. A few researchers have worked on scheduling of public transit systems, especially bus systems, as elucidated below.

Peng and Huang (2000) developed a web-based transit information system design using GIS to integrate web serving. GIS processing, network analysis and database management. The design is interactive and users can interact with information on transit routes, schedules and trip itinerary planning. They proposed a path finding algorithm for transit network to handle special characteristics like time-dependent services, common bus lines on same street and non symmetric routing with respect to an origin destination pair.

Shafahi and Khani (2010) studies the transit network scheduling problem and aims to minimize the waiting time at transfer stations. They propose a mixed integer programming model for departure times of vehicles for minimizing transfer times and a genetic algorithm that can help in case of larger networks. A case study of the Mashhad City bus network is given to explain and evaluate the model and genetic algorithm.

Hadas and Ceder (2010) proposes a dynamic programming model to improve transit service reliability by proper coordination of public transit vehicles for optimally reducing transfer time. The results obtained from the optimization model are validated using simulation.

Ceder (2011) studies the public transport vehicle scheduling problem and considers relation between characteristics of a trip and the vehicle type required for each so that the cost is minimized. A heuristic algorithm is developed based on the deficit function theory. The case of the Egged bus company in Israel is used to explain the algorithm for network route design, timetable development and vehicle scheduling and crew scheduling.

The above studies have used optimization techniques for scheduling public transit systems. However, the scheduling of para transit systems needs to be dynamic and stochastic queuing models can be used to understand the system. Some researchers have used queuing models, both deterministic and stochastic, to estimate delays for different types of transport systems including roads, railways and airways as explained below.

Hendrickson et al (1981) models schedule delay in a deterministic setting based on user equilibrium concepts and deterministic queuing theory to minimize total user delay. They considered the arrival time of users at a bottleneck in morning hours in cases of on-time arrival and late arrival. They used numerical examples to illustrate the queuing scenario and determine the delay and system optimal flows. They also identified related research issues.

Turnquist & Daskin (1982) proposed queuing models for estimating delay to rail cars in passing through yards, both while waiting for classification and also during connection to an appropriate outbound train, to obtain the mean and variance of delay times. The models are then used in an example application to draw inferences regarding the effectiveness of alternative strategies for dispatching trains between yards.

Hansen (2002) showed how runway delay externalities can be explained using a deterministic queuing model. The author estimated the delay impact of each arrival flight on every other arriving flights at Los Angeles International Airport to suggest variable pricing of runway use at the airport.

[1] Corresponding author: vijaya@cimp.ac.in

Hansen et al (2009) used both deterministic and stochastic queuing models to understand queuing behaviour at airports and predict delays over a wide range of congestion levels.
The objective of the work is to suggest a dynamic framework for optimal scheduling of para-transit operations considering the randomness in arrival of passengers.
The next section describes the methodology adopted for the study. Section 3.0 illustrates the methodology with an example. Section 4.0 gives the summary and conclusions of the work.

2. Methodology

As mentioned earlier, most research in the past have focused on optimal scheduling and routing of transit systems, usually bus transit systems. Scheduling of para transit systems will be different from bus transit systems as the nature of the two systems is very different. The bus transit system has buses of much higher capacity. The buses usually have designated start time at pre defined intervals, usually defined by the demand during that hour, and designated stoppages. The start time does not dynamically change on a day based on the demand. Usually for para-transit systems like autos no formal schedules exist for start and stop and scheduling is dynamic and demand based. Vehicles start only when they are full. The arrival of passengers at a stop is a random event. It is difficult to optimize the schedules of autos so that the waiting times can be minimized. The application of queuing theory seems relevant in this context.
In this article, the applicability of queuing model for scheduling para transit systems is explained with the help of an example of autos starting from a key point of the city of Patna in the state of Bihar, India. The detailed approach of the methodology used is illustrated in Fig. 1.

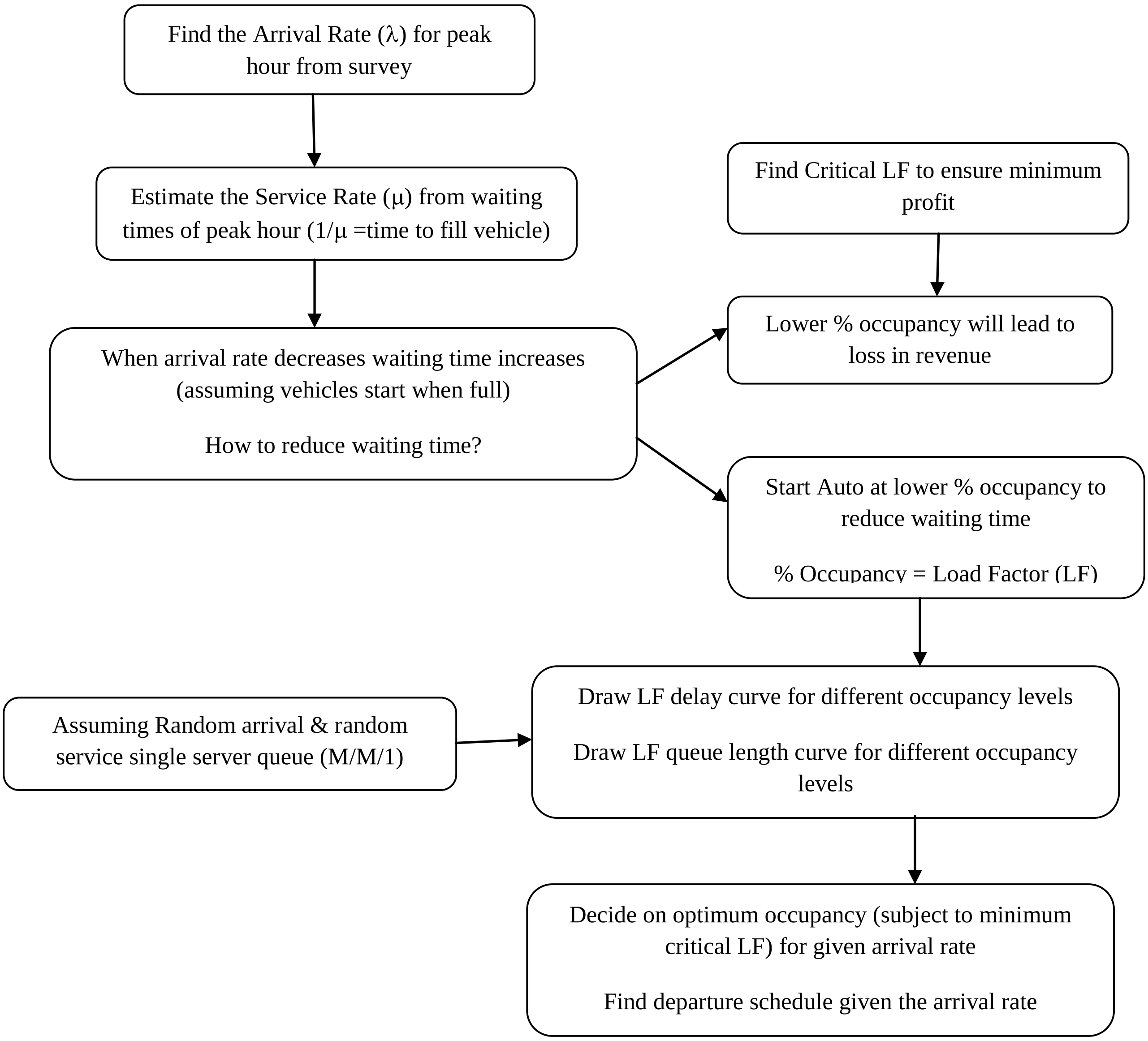


Fig. 1.
Methodology of overall work

The passenger arrival is random and the transit vehicles start when they are full. In order to take both these constraints in the scheduling model better, the problem can be viewed as a queuing model where passengers (customers) come to the starting point (the server) and wait till they are served i.e. they get into an auto and the auto departs for the required destination. It is assumed here that there are enough number of autos and availability is not a problem. Also, the autos wait at the starting point and get filled up one at a time. The service time is the time the passenger waits in the auto, or the time taken by the auto to get filled. This is linked to the arrival rate as the time taken by auto to get filled is a function of arrival rate. Thus the service time rate is also random. The transit vehicle operation can be viewed as a single server system.

The M/M/1 queuing model, the classic stochastic queuing model, may be applied in this situation. M refers to a memoryless (or Markovian) distribution, that is, to the exponential distribution (Ravindran, Phillips, & Solberg, 1987). Therefore, the M/M/1 queue is a model with exponentially distributed interarrival times, which implies that the arrivals are Poisson distributed, service times are exponentially distributed and there is a single server. It may also be assumed that the queue discipline is *first come, first serve* (FCFS). The capacity of the system and size of the source population can be assumed to be infinite. The arrival rates of passengers are independent of each other and can be assumed to follow a Poisson distribution. It may be obtained from the number of passengers arriving at a starting point during a rush hour or otherwise estimated from the number of autos leaving a node for a given destination, assuming 6 passengers are there in the auto. The service rate may be estimated from the average time intervals between departures.

The arrival rate (λ) of passengers at a given start point during the peak hours may be found from survey. The service rate (μ) may be estimated from the waiting times during peak hours, where $1/\mu$ is the time required to fill a vehicle.

If the average waiting time of a passenger at a given start point is known, it can be assumed that the arrival rate is Poisson distributed, Probability of i customers coming at a given hour may be found out. Also probability of i customers in queue can be found out. The mean waiting time in the queue can be estimated. Also the mean utilization of server and mean throughput rate can be estimated. The time for start of a para-transit can also be estimated.

From the above model 3 situations can arise

1. $\lambda = \mu$ which indicates optimum utilization. This means that user waiting time is minimum and the transit vehicles run at full capacity ensuring maximum profit for transit operators. The passenger arrival is equal to the optimum achievable service rate. The supply and demand are in equilibrium. This is easy to conceptualize.
2. $\lambda > \mu$ which indicates that the demand cannot be met in the system.
3. $\lambda < \mu$ which indicates that the system is not functioning optimally. The passenger arrival is less than the optimum achievable service rate. Due to decrease of arrival rate the waiting times of passengers increase as the time to get auto filled increases. Also the transit vehicle owners loose the revenue or run at a loss if the auto runs partially filled to minimize user waiting time. The transit vehicle scheduling in such case is a challenging scenario.

The suggested methodology for scheduling considers the case when $\lambda < \mu$. This can be done considering two objectives:

1. Reduce waiting time of passengers in the transit-vehicle
2. Ensure no loss due to vehicle not getting filled to capacity

The load factor, also the percentage occupancy of the auto, is shown in equation 1.

$$\rho = \frac{\lambda}{\mu} \tag{1}$$

Where λ is the arrival rate and μ is the service rate.

The service rate has to be greater than or equal to the arrival rate ($\lambda/\mu<1$) for the passengers to be served during the rush hour. However, as the arrival rate decreases the waiting time increases for passengers. The autos need to start at lower occupancy rates to reduce waiting times. However, this will lead to loss in revenue. An optimum load factor needs to be estimated that will minimize waiting times while also ensuring a minimum profit. The optimal number of passengers in an auto may be found from the vehicle operating cost, minimum desired profit and fare per passenger as shown in equation 2. A critical load factor is determined from the optimal number of passengers and vehicle capacity as shown in equation 3.

Initially we need to find the load capacity utilization (LF) can be estimated from equations below.

$$N_{Popt} = \frac{Total\ vehicle\ operating\ cost + Minimum\ desired\ profit}{Fare\ per\ passenger} \tag{2}$$

$$LF = \frac{N_{Popt}}{Vehicle\ Capacity} \tag{3}$$

Considering no loss criteria, transit vehicle should start when the transit vehicle is filled to load capacity utilization.

Assuming random arrival and random service single server queue (M/M/1) the delays and queue lengths are found for different occupancy levels. The length of the queue (Lq) can be obtained using equation 4 and waiting time in the queue can be obtained from equation 5.

$$L_q = \frac{\rho^2}{1-\rho} \tag{4}$$

$$W_q = \frac{L_q}{\lambda} \tag{5}$$

The delay versus load factors and queue length versus load factors are plotted to find the optimal load factor. The cut-off points are decided above which the delay and queue length increases exponentially, as explained later. The two load factors, one from cost and other from waiting times (delay) are compared to decide on the optimum critical load factor. This may be then used to decide the optimum occupancy level for a given arrival rate. The departure schedules can then be decided that will take care of arrival rates of passengers at a given hour while minimizing the waiting times and also ensuring a minimum profit for the auto drivers.

3. Illustration of Methodology

The concept is explained with the help of a small case study. For the autos of a given route from a given starting point (Gandhi Maidan), the arrival rates of passengers have been estimated as 4.4 per minute i.e. λ = 4.4 per minute from survey, and the service time is estimated to be 4.63 minute from waiting time survey.

Table **1** shows the waiting times in queue in minutes for different load factors.

Table 1
Waiting time & Queue lengths for different load factors

Load Factor	Waiting time in queue (Wq)	Ln(Wq)	Length of queue (Lq)	ln(Lq)
0.5	0.11	-2.17	0.50	-0.69
0.55	0.15	-1.88	0.67	-0.40
0.6	0.20	-1.59	0.90	-0.11
0.65	0.27	-1.29	1.21	0.19
0.7	0.37	-0.99	1.63	0.49
0.75	0.51	-0.67	2.25	0.81
0.8	0.73	-0.32	3.20	1.16
0.85	**1.09**	0.09	**4.82**	1.57
0.9	1.84	0.61	8.10	2.09
0.95	4.10	1.41	18.05	2.89
1	2.27E+14	33.06	1E+15	34.54

Fig. 2. shows the waiting times (in natural log scale) for various load factors.

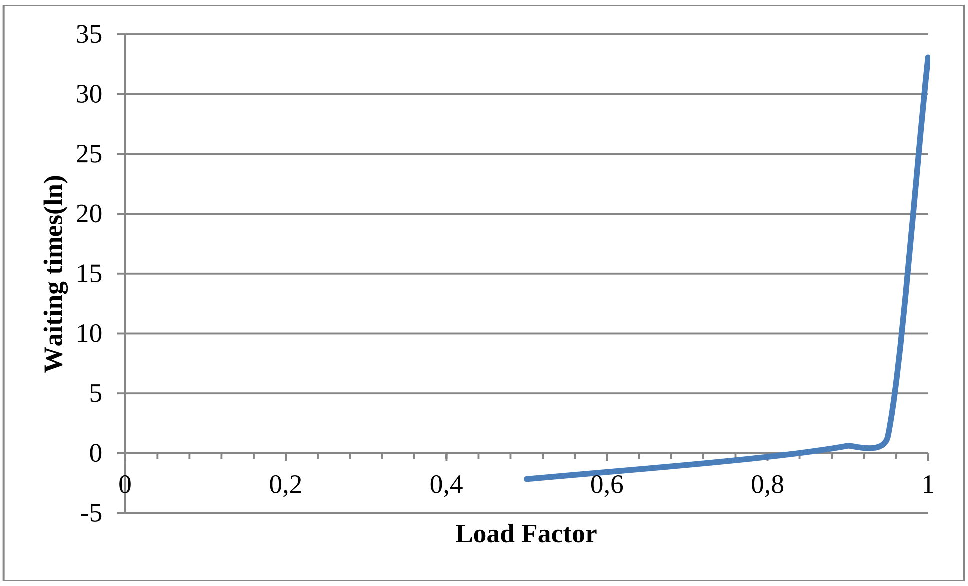


Fig. 2.
Waiting Time for different load factors

Fig. 2. shows the length of queue (in natural log scale) for various load factors.

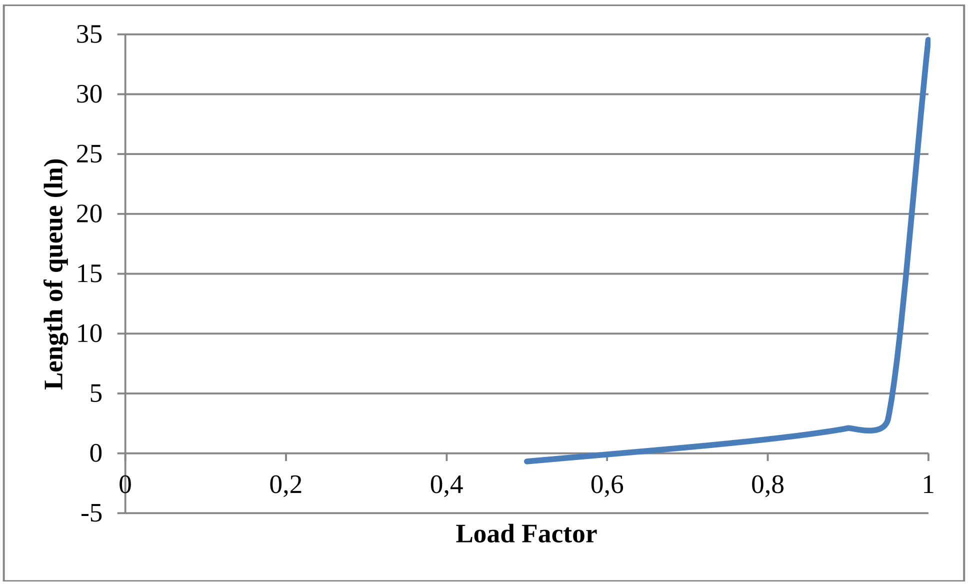


Fig. 3.
Queue lengths for different load factors

The observed load factor is 0.95. It may be observed from the above two figures that the waiting time and queue length increases exponentially above a load factor of 0.95. However, it may also be observed that above a load factor of 0.85, the queue length becomes more than double and waiting time is also almost double. So, the load factor 0.85, at which queue length is 4.82, can be taken as the critical load factor. So, looking at the waiting times, it may be recommended that autos start when 5 passengers arrive.
The cost of the trip can also be used to determine the optimal number of passengers required to start an auto. The cost of running an auto per km is can be estimated as Rs.3.5, using IRC method (IRC, 2009). So for a 8 km trip, the total cost is Rs.28. The fare per passenger is Rs.8 for the same distance. So assuming a 20% profit margin, the optimal number of passengers may be estimated from equation 2 as 4.2. So, if autos start with 5 passengers, they can make a profit of 39%.

4. Summary and Conclusions

Scheduling of para transit systems like autos in India is a difficult problem, different from other types of transit systems like buses. The scheduling of para transits is a dynamic process that can be modelled using the stochastic queuing model M/M/1. The scheduling may be done using a queuing model when arrival rates of passengers, service rates and transit costs can be estimated by survey method. The aim is to minimize waiting times of passengers while ensuring a minimum desired profit for the auto drivers. The case study of autos in Patna, Bihar, India is used to illustrate the suggested methodology.

References

Ceder, A. 2011. Public-transport vehicle scheduling with multi vehicle type, *Transportation Research Part C* , 19: 485-497.
Ernst, A.T.; Jiang, H.; Krishnamoorthy, M.; Sier, D. 2004. Staff scheduling and rostering: A review of applications, methods and models, *European Journal of Operational Research*, 153: 3-27.
Hadas, Y.; Ceder, A. 2010. Optimal coordination of public transit vehicles using operational tactics examined by simulation, *Transportation Research Part C*, 18: 879-895.
Hansen, M. 2002. Micro-level analysis of airport delay externalities using deterministic queuing models: a case study, *Journal of Air Transport Management*, 8: 73-87.
Hansen, M.; Nikoleris, T.; Lovell, D.; Vlachou, K.; Odoni, A. 2009. Use of Queuing Models to Estimate Delay Savings from 4D Trajectory Precision. In *Proceedings of Eighth USA/Europe Air Traffic Management Research and Development Seminar*.
Hendrickson, C.; Kocur, G. 1981. Schedule Delay and Departure Time Decisions in a Deterministic Model, *Transportation Science*, 15(1): 62-77.
IRC. 2009. *Manual on Economic Evaluation of Highway Projects in India.* New Delhi.
Peng, Z.; Huang, R. 2000. Design and development of interactive trip planning for web-based transit information systems, *Transpotation Research Part C*, 409-425.

Ravindran, A.; Phillips, D.T.; Solberg, J.J. 1987. *Operations Research: Principles and Practice.* John Wiley & Sons.

Shafahi, Y.; Khani, A. 2010. A practical model for transfer optimization in transit network: Model formulations and solutions, *Transportation Research Part A,* 44: 377-389.

Turnquist, M.A.; Daskin, M.S. 1982. Queuing Models of Classification and Connection Delay in Railyards, *Transportation Science*, 16(2): 207-230.

ANALYSIS AND ASSESSMENT OF THE TRANSPORT VOLUME BY ROAD VEHICLES IN THE ADRIATIC-IONIAN REGION

Ivan Ivković[1], Dragan Sekulić[2], Dušan Mladenović[3]
[1,2,3] University of Belgrade-Faculty of Transport and Traffic Engineering, Belgrade, Serbia

Abstract: The paper presents the results of research that have been reached in the framework of the implementation of activities in work package "Assessment of the Adriatic port system and its integration with hinterland" of the EA Sea-Way project. Analysis and assessment of the transport volumes by passenger and freight road vehicles was carried out for the six countries in the Adriatic-Ionian Macro-Region: Albania, Croatia, Greece, Italy, Montenegro and Slovenia. Methodological approach included the specifics of the area at the national level and changes in transport demands on road infrastructure during the period from 2005 to 2030. Assessment and quantification of changes in transport volumes was carried out for the short-term (five-year) and the medium-term period (ten-year).

Keywords: road vehicles, transport volume, road network, assessment.

1. Introduction

The main objective of the EA Sea-Way project is development of new cross border, sustainable and integrated transport services and the significant improvement of physical infrastructures related to those new services. This should lead to improve the accessibility and the mobility of passengers across the Adriatic-Ionian area and its hinterland. Since the EA Sea-Way project brings together all modes of transport, analysis of road transport indicators is an essential part of the activities. The traffic volume expressed in motor vehicle kilometres (passengers veh-km or freight veh-km) or transport volumes expressed as passenger-kilometres (PKM) or tonne-kilometres (TKM) can be presented as indicators of sustainable transport from the standpoint of providing economic and consumer benefits (Litman, 2016). On the other hand, the dominance of this transport mode in relation to others and more pronounced negative impact of road transport on the environment puts them into indicators that do not have a prefix "sustainable" (Dobranskyte-Niskota et al., 2007). For these reasons, their monitoring, analysis and assessment are becoming increasingly important. Analysis and assessment of realized traffic and transport volumes must be able to adequately provide decision makers with informative signals on the multiplicity of issues involved. (May et al., 2008; Castillo and Pitfield, 2010; Torok, 2013). Therefore, these indicators are irreplaceable data on which decisions are taken in order to create a sustainable transport system using different transport models. Bearing in mind the above mentioned, in this paper was carried out an analysis and assessment of transport volumes in the six countries of the Adriatic-Ionian Macro-Region: Albania, Croatia, Greece, Italy, Montenegro and Slovenia. The results of research are input data for the complete and successful implementation of sustainable development of passenger transport models for the Adriatic basin, capacity building and further pilot actions.

2. Methodological approach

Fig. 1 shows the methodological approach that was used in the analysis and assessment of the transport volume by road vehicles in the Adriatic-Ionian Macro-Region.

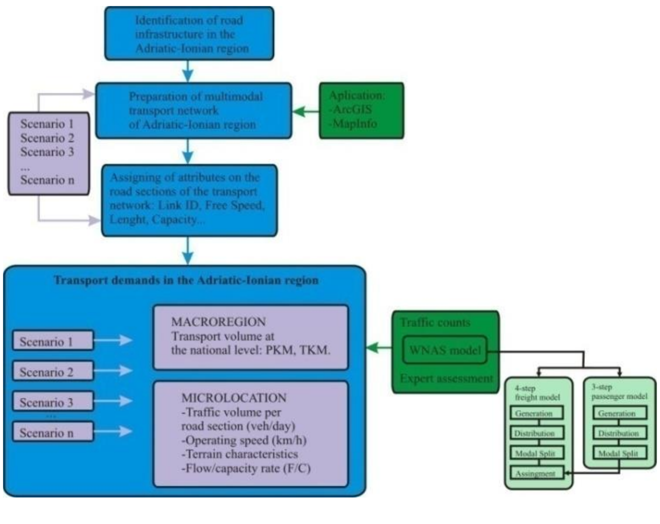


Fig. 1.
Methodological approach for analysis and assessment of the transport volume by road vehicles

[1] Corresponding author: i.ivkovic@sf.bg.ac.rs

In the first step, methodological approach includes the identification of road infrastructure which is the subject of research. Fig. 2 shows the road network of the Adriatic-Ionian Macro-Region

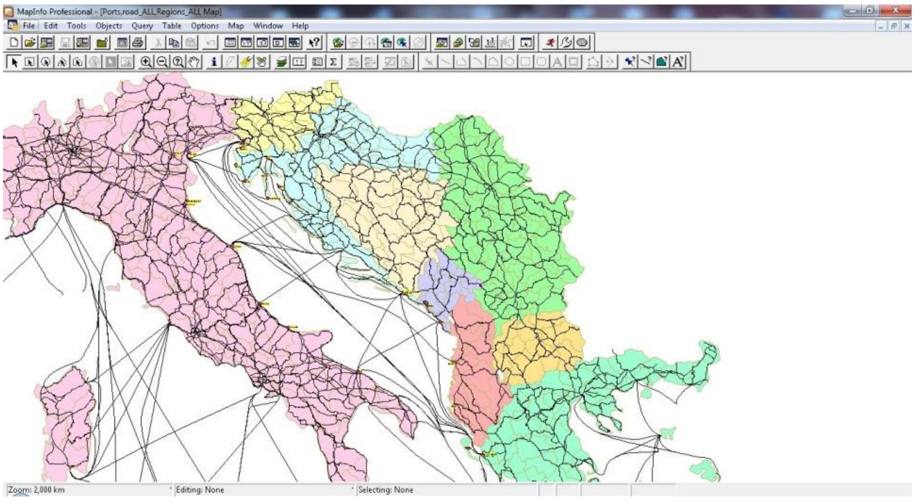


Fig. 2.
Road network of the Adriatic-Ionian Macro-Region

The National Road Network in Albania is about 18,000 km long including 3,636 km of National Roads, 10,500 km of interurban roads, and the rest of 4,000 km is under the jurisdiction of autonomous units, enterprises or companies. The primary road network is about 1,138 km with nine main connections which made up the basis of the network. The secondary network is 1,998 km long.

In Croatia, two major road corridors extend from the capital city Zagreb. The first main corridor (highway A1) provides directions to the west and south west, i.e. through Karlovac to the Croatian coast with the value of the average annual daily traffic (AADT) of approximately 30,000 veh/day (average for the period 2010-2013). The corridor includes the arterial that bypasses Bosiljevo, namely, to Rijeka (highway A6) with AADT value of around 12,000 veh/day and to Zadar, Šibenik and Split (continued highway A1) with AADT value of around 13,000 veh/day. The second main corridor spreads from Zagreb across Nova Gradiška, Slavonski Brod (highway A3) to the Lipovac border crossing with AADT values of around 20,000 veh/day, 13,500 veh/day, 10,500 veh/day, 6,000 veh/day, respectively.

Greece’s road network covers 117,000 kilometres in total (mainland and islands). Total road network includes motorways, highways, and main or national roads, secondary or regional roads, and all other roads in a country. A motorway is a road designed and built for motor traffic that separates the traffic flowing in opposite directions. The main road axes are: Athens- Thessaloniki (E75); Athens-Corinth (E94); Corinth-Patras (E65); Corinth-Tripoli-Kalamata (E65); Patras-Pyrgos-Olympia (E55); Thessaloniki-Kavala-Alexandroupoli (E90); Igoumenitsa-Alexandroupoli (Egnatia Odos Motorway); Chania-Agios Nikolaos (Crete E75).

Traffic corridors with the dominant values of the traffic flow spread on Italian territory at around 7000 km of highways divided into 35 road sections. Ports within Adriatic-Ionian Macro-Region that are analyzed in the EA Sea-Way project (Trieste, Chioggia, Ravenna, Ancona, Termoli and Bari) are located near or lie on certain highways. The port of Trieste is located on the highway A4 Torino-Trieste whose length is 524 km with an AADT value of over 100,000 veh/day. The port of Chioggia is located near the highway A13 Bologna-Padova with an AADT value of around 60,000 veh/day and A57 that passes around Venice with similar characteristics as the highway A4. In addition to the port of Ravenna at a distance of approximately 30 km stretches highway A14 Bologna-Taranto with a total length of 743 km and with an AADT value of around 45,000 veh/day. Close to the A14 road section are also located ports of Ancona, Termoli and Bari.

In Montenegro, they are six road corridors where 5 corridors extend from the capital city Podgorica: The first main corridor extends northwards towards Kolašin with an average AADT value of about 5,700 veh/day. The second main corridor extends northwest to Nikšić with an average AADT value of about 6,500 veh/day. The third main corridor extends westward to the Cetinje with an average AADT value of about 8,000 veh/day. The fourth main corridor extends southwest to the port of Bar over Mišići, with an average AADT value of approximately 8,300 veh/day. The sixth corridor extends over Adriatic coast from Herceg Novi to Ulcinj with an average AADT value of about 7,000 veh/day. Geographical position of the port of Bar places port of Bar close to the main node of coridor from Adriatic coast and corridor extends southwest to the port of Bar over Mišići.

In Slovenia, four major road corridors extend from the capital city Ljubljana. The first main corridor (highway A2) extends northwest towards Jasenice over Kranj and Bled with an average AADT value of about 30,000 veh/day. The second main corridor (highway A1) extends northeast to Maribor over Celje with an average AADT value of about 38,000 veh/day. The third main corridor (highway A2) extends southeast to the Novo Mesto with an average AADT value of about 25,000 veh/day. The fourth main corridor (highway A1) extends southwest to the port of Koper over Postojna, with an average AADT value of approximately 38,000 veh/day.

In the second step, the preparation of road network was conducted. This includes the allocation of attributes on the individual road sections: length, number of lanes in one direction, operating speed, design speed, hourly capacity, etc. Based on statistical data, the current state of realized transport volumes by vehicle categories (passenger cars, buses and trucks) was obtained in the period from 2005 to 2012 for the above mentioned six countries. The assessment of transport volumes in 2020 and 2030 was based on the WNAS (WorldNet Assignment) model. WNAS model is composed of two sub-models: three-step passenger model and four-step freight models. WNAS model takes into account a number of influential factors to the actual transport volumes on the road network: traffic-geographical position of the region, socio-economic and socio-political characteristics, deployment of activities, the characteristics of the transport network, the parameters of passengers and freight flows. Quantification of changes in transport volumes is carried out according to two scenarios: an optimistic scenario which involves increasing of transport volumes for 10% in relation to the real scenario and the pessimistic scenario which involves decreasing of transport volumes for 10% in relation to the real scenario. The real scenario represents the realized (assessed) transport volumes for 2020 and the 2030 in the countries of the Adriatic-Ionian Macro-Region obtained by using WNAS model.

3. Results and analysis

Table 1 shows the realized and assessed transport volumes of passenger cars, buses and trucks on the road network of the Adriatic-Ionian Macro-Region.

Table 1
Realised and forecasted transport volumes of different vehicle categories in Adriatic–Ionian Macro-Region (1000 x milion PKM/TKM-realistic scenario)

Passenger cars (1000 x million PKM-realistic scenario)														
	2005	2005	2006	2007	2008	2009	2010	2011	2012	Change 10/11	Change 10/12	2020	2030	Change 10/20	Change 10/30
		Model										Model	Model		
GR	85.00	83.21	90.00	95.00	100.00	101.30	99.60	98.32	96.93	-1.28	-2.68	91.70	99.20	-7.93	-0.40
HR	24.00	25.42	25.00	26.00	27.00	26.80	25.70	25.24	26.15	-1.78	1.74	34.60	43.90	34.63	70.82
IT	677.01	703.48	676.26	677.06	676.36	719.91	698.39	665.82	578.67	-4.66	-17.14	801.40	865.30	14.75	23.90
SI	22.51	22.43	23.01	24.36	24.88	25.78	25.64	25.49	25.30	-0.58	-1.30	29.00	34.90	13.12	36.14
ME	3.81	5.46	3.97	4.13	4.29	4.25	4.08	3.93	3.98	-3.67	-2.51	5.70	6.20	39.72	51.98
AL	8.30	8.32	7.46	7.47	7.46	7.94	7.62	7.41	6.35	-2.79	-16.65	8.80	9.30	15.43	21.99
Buses (1000 x million PKM- realistic scenario)															
	2005	2005	2006	2007	2008	2009	2010	2011	2012	Change 10/11	Change 10/12	2020	2030	Change 10/20	Change 10/30
		Model										Model	Model		
GR	21.70	21.76	21.80	22.00	22.10	20.92	21.10	21.16	21.10	0.29	-0.02	16.39	16.13	-22.32	-23.53
HR	3.40	3.51	3.54	3.81	4.09	3.44	3.25	3.15	3.25	-3.18	0.02	3.82	4.42	17.73	35.93
IT	100.95	100.05	103.05	102.66	102.44	101.71	102.22	102.44	102.81	0.21	0.58	120.90	118.79	18.28	16.21
SI	3.06	3.22	3.13	3.24	3.15	3.20	3.18	3.24	3.24	1.92	1.70	3.29	3.60	3.34	13.17
ME	0.09	0.11	0.10	0.11	0.12	0.10	0.08	0.08	0.11	-1.23	38.27	0.16	0.15	92.75	90.79
AL	1.02	1.10	0.91	0.91	0.91	0.97	0.94	0.89	0.82	-5.09	-12.68	1.01	0.98	7.11	4.36
Freight vehicles (1000 x million TKM- realistic scenario)															
	2005	2005	2006	2007	2008	2009	2010	2011	2012	Change 10/11	Change 10/12	2020	2030	Change 10/20	Change 10/30
		Model										Model	Model		
GR	32.50	23.91	34.00	27.79	28.85	28.59	29.82	20.60	20.84	-30.92	-30.11	38.80	44.90	30.14	50.60
HR	9.33	9.50	10.18	10.50	11.04	9.43	8.78	8.93	8.65	1.66	-1.49	14.60	18.40	66.29	109.57
IT	211.80	192.82	187.07	179.41	180.46	167.63	175.78	142.84	124.02	-18.74	-29.45	229.30	248.10	30.45	41.15
SI	11.03	10.80	12.11	13.73	16.26	14.76	15.93	16.44	15.89	3.19	-0.27	14.80	18.50	-7.10	16.13
ME	0.13	0.55	0.13	0.13	0.14	0.18	0.17	0.10	0.08	-38.92	-54.49	0.64	0.84	283.23	400.00
AL	1.12	1.30	1.10	1.16	1.17	1.17	1.18	1.19	1.26	1.02	6.89	4.90	6.10	317.02	419.15

Sources: EC, 2009; EC, 2010; EC, 2011; EC, 2012; EC, 2013; EC, 2014; ITF, 2015; WNAS model.

Table 2 shows the changes of the transport volumes in relation to the year 2010 in Croatia for all three scenarios.

Table 2
Changes of the transport volumes in relation to the year 2010 in Croatia (1000 x million PKM/TKM/%)

Passenger cars											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
34.60	43.90	34.63	70.82	31.14	39.51	21.17	53.74	38.06	48.29	48.09	87.90
Buses											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
3.82	4.42	17.73	35.93	3.44183	3.97392	5.95	22.33	4.206681	4.857014	29.50	49.52
Trucks											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
14.60	18.40	66.29	109.57	13.14	16.56	49.66	88.61	16.06	20.24	82.92	130.52

The declining trend in realised transport volume of passenger vehicles (passenger cars and buses in 2011), and trucks (2012) stagnation (buses 2012) or a slight growth (passenger cars for the year 2012 and trucks in 2011) in the case of Croatia are in line with the trend of actual transport volume on road sections in the port area Rovinj, Pula, Krk, Mali Lošinj, Rab, Split and Dubrovnik (Ivkovic, 2015) observed within EASEA-WAY project. Therefore the changes at the state level can be characterized as relevant for assessing the growth or decline of traffic in the future (short-term or medium-term period) in the Adriatic-Ionian Macro-Region. Major discrepancies are evident during the summer months of 2011 and 2012, which was expected given the fact that the data in Table 1 refer to the full-year period of observation. From Table 1 it can be seen that in the short term (up to 2020) according to the results of the model, expected growth in passenger kilometres is 21.17% for passenger cars and 5.95% for buses compared to 2010. In relation to trucks, it is expected for 2020 tonne kilometres growth of 66.29% compared to 2010 (Table 1). In 2030, the expected growth in transport volume based on model approximation is 70.82% (passenger cars), 35.93% (buses) and 109.57% (trucks).In the pessimistic scenario (Table 2) the characteristic growth rates have the following values: for passenger cars relative to 2010, short term/long term: 21.17%/53.74%; for buses 5.95%/22.33%; for trucks 49.66%/86.61%; while the optimistic scenario equivalent values are: for cars 48.09%/87.90%;, for buses 29.50%/49.52%; for trucks 82.92%/130.52%. It should be noted that the provided changes are related to changes in traffic volume in regions of Croatian ports (Rovinj, Pula, Krk, Mali Lošinj, Rab i Dubrovnik) expressed in tonne kilometres or passenger-kilometres.

Table 3 shows the changes of the transport volume in relation to the year 2010 in Italy for the three scenarios.

Table 3
Changes of the transport volumes in relation to the year 2010 in Italy (1000 x million PKM/TKM/%)

Passenger cars											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
801.40	865.30	14.75	23.90	721.26	778.77	3.27	11.51	881.54	951.83	26.22	36.29
Buses											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
120.90	118.79	18.28	16.21	108.8116	106.9139	6.45	4.59	132.992	130.6725	30.10	27.84
Trucks											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
229.30	248.10	30.45	41.15	206.37	223.29	17.41	27.03	252.23	272.91	43.50	55.26

The declining trend in actual transport volume of passenger vehicles (passenger cars and trucks in 2011 and 2012), or stagnation (buses 2011 and 2012) in the case of Italy are in line with the trend of actual transport volume on road sections in the port area (Trieste, Chioggia, Ravena, Anconna, Termoli and Bari) observed within EASEA-WAY project. As opposed to Croatia, there is no significant deviations in the third quarter of 2011 and 2012, which was expected given the fact that the third quarter includes two months out of the season (Ivković, 2015) while data of transport volumes from Table 1 relating to the one year period observations. Therefore the changes at the state level can be characterized as relevant for assessing the growth or decline of traffic in the future (short-term or medium-term period) in the Adriatic-Ionian Macro-Region. From Table 1 it can be seen that in the short term (up to 2020) according to the results of the model, expected growth in passenger kilometres is 3.27% for passenger cars and 6.45% for buses compared to 2010. In relation to trucks, it is expected for 2020 tonne kilometres growth of 30.45% compared to 2010. In 2030, the expected growth in transport volume based on model approximation is 23.90% (passenger cars), 16.21% (buses) and 41.15% (trucks).In the pessimistic scenario (Table 3) the characteristic growth rates have the following values: for passenger cars relative to 2010, short term/long term: 3.27%/11.51%; for buses 6.45%/4.59%; for trucks 17.41%/27.03%; while the optimistic scenario equivalent values are: for cars 26.22%/36.29%; for buses 30.10%/27.84%; for trucks 43.50%/55.26%. It should be noted that the provided changes are related to changes in traffic volume in regions of Italian ports expressed in tonne kilometres or passenger-kilometres.

Tables 4, 5, 6 and 7 show the changes of the transport volume in relation to the year 2010 in the whole territory of countries: Slovenia, Montenegro, Albania and Greece. As it was mentioned above, for Croatia and Italy in terms of the relevance of data for the whole territory of entire countries, it is sufficient to provide analysis of the rate of increase or decrease of the transport volumes for different scenarios by tables.

Table 4

Changes of the transport volumes in relation to the year 2010 in Slovenia (1000 x million PKM/TKM/%)

Passenger cars											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
29.00	34.90	13.12	36.14	26.1	31.41	1.81	22.52	31.9	38.39	24.43	49.75
Buses											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
3.29	3.60	3.34	13.17	2.960309	3.241947	-7.00	1.85	3.618155	3.962379	13.67	24.49
Trucks											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
14.80	18.50	-7.10	16.13	13.32	16.65	-16.39	4.51	16.28	20.35	2.19	27.74

Table 5

Changes of the transport volumes in relation to the year 2010 in Montenegro (1000 x million PKM/TKM/%)

Passenger cars											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
5.70	6.20	39.72	51.98	5.13	5.58	25.75	36.78	6.27	6.82	53.70	67.18
Buses											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
0.16	0.15	92.75	90.79	0.140514	0.139085	73.47	71.71	0.17174	0.169992	112.02	109.87
Trucks											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
0.64	0.84	283.23	400.00	0.576	0.7515	244.91	350.00	0.704	0.9185	321.56	450.00

Table 6
Changes of the transport volumes in relation to the year 2010 in Albania (1000 x million PKM/TKM/%)

Passenger cars											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
8.80	9.30	15.43	21.99	7.92	8.37	3.89	9.79	9.68	10.23	26.97	34.19
Buses											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
1.01	0.98	7.11	4.36	0.90524	0.882	-3.60	-6.07	1.106405	1.078	17.82	14.80
Trucks											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
4.90	6.10	317.02	419.15	4.41	5.49	275.32	367.23	5.39	6.71	358.72	471.06

Table 7
Changes of the transport volumes in relation to the year 2010 in Greece (1000 x million PKM/TKM/%)

Passenger cars											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
91.70	99.20	-7.93	-0.40	82.53	89.28	-17.14	-10.36	100.87	109.12	1.28	9.56
Buses											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
16.39	16.13	-22.32	-23.53	14.75093	14.52122	-30.09	-31.18	18.02892	17.74816	-14.55	-15.89
Trucks											
Realistic scenario				Pessimistic scenario				Optimistic scenario			
2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30	2020	2030	change 10/20	change 10/30
Model	Model	%	%	Model	Model	%	%	Model	Model	%	%
38.80	44.90	30.14	50.60	34.92	40.41	17.12	35.54	42.68	49.39	43.15	65.65

4. Conclusions

Based on the presented results and analysis, the conclusions of this research are as follows:

- Distribution of transport volumes at the level of the Adriatic-Ionian Macro-Region is extremely heterogeneous. By far the biggest transport volumes was realized in Italy, about 680,000 million PKM in 2012 (from this value, over 78% was realized by passenger cars). The lowest passenger transport volumes were realized in Montenegro and Albania with the amount of approximately 4,000 and 7,000 million PKM, respectively. Similar values of around 25,000 million PKM were realized in Croatia and Slovenia. In Greece was realized transport volumes about 5.5 times lower than in Italy, in the amount of about 120,000 PKM. A similar situation exists in the case of freight transport volumes. Italy leads with a share of 72% of the total value. Following are Greece, Slovenia and Croatia with the amount of 12%, 9% and 5% respectively. Freight transport volumes in Albania and Montenegro are negligible, less than 1%,
- It is expected approximately constant value of passenger car PKM in Greece up to 2030 in the real scenario. In the same period bus PKM will decrease. The largest increase in passenger car PKM is expected in the medium-term period in Croatia, Montenegro and Slovenia (71%, 52%, and 36% respectively). A significant increase of bus PKM in the medium-term period is expected in Montenegro in the amount of 91%. From the standpoint of freight transport volumes, the highest growth in the medium-term period is characteristic for Albania and Montenegro (almost four times higher value than in 2010),
- In the short-term period, the results of the assessment indicate the lower realization of passenger car transport volumes by about 8% in relation to the medium-term period, throughout the whole macro-region. Bus

transport volumes are mainly slightly changed except Croatia and Slovenia where the rates of decline will amount from 8% to 14%. The decreasing of the freight transport volumes in the short-time period (compared to medium-term period) will be in the range of about 20 to 24% for Albania, Montenegro, Croatia and Slovenia. Somewhat smaller percentages are characteristic for Italy and Greece, 7% and 13% respectively,

- In this paper are analyzed two hypothetical scenarios which indicate the maximum possible variation in the quantification of realized road transport volumes in the Adriatic-Ionian Macro-Region region. Variations are valid for assessing of transport volumes in the areas of ports that are observed within EA Sea-Way project (Trieste, Chioggia, Ravenna, Anconna, Termoli, Bari, Koper, Bar, Vlore, Sarande and Igoumenitsa). For the Croatian ports (Rovinj, Pula, Krk, Mali Lošinj, Rab, Split and Dubrovnik) must be additionally to take into account seasonal traffic flows variations in the period 1 July to 31 August.

Acknowledgments

This paper is based on the Europe Adriatic EA Sea-Way project, co-financed by the European Union in the framework of the IPA Adriatic Cross-Border Cooperation Programme 2013-2016.

References

Castillo, H; Pitfield, D.E. 2010. ELASTIC – A methodological framework for identifying and selecting sustainable transport indicators, *Transportation Research Part D: Transport and Environment*, 15: 179-188.

Dobranskyte-Niskota, A.; Perujo, A.; Pregl, M. 2007. *Indicators to Assess Sustainability of Transport Activities*, European Commission, Brussels, Belgium.

EC 2009. *EU energy and transport in figures*, European Commission, Brussels, Belgium.

EC 2010. *EU energy and transport in figures*. European Commission, Brussels, Belgium.

EC 2011. *EU transport in figures*, European Commission, Brussels, Belgium.

EC 2012. *EU transport in figures*, European Commission, Brussels, Belgium.

EC 2013. *EU transport in figures*, European Commission, Brussels, Belgium.

EC 2014. *EU transport in figures*, European Commission, Brussels, Belgium.

ITF 2015. Road transport-International Transport Forum. Available from Internet: <http://www.itf-oecd.org/all-transport>.

Ivković, I. 2015. Transport indicators within the areas of ports in the Adriatic region: motor vehicle traffic volumes and analysis. In *Proceedings of 17th International conference on transport science, Portorož, Slovenia*, 118–131.

Litman, T. 2016. *Developing Indicators for Sustainable and Livable Transport Planning*, Victoria Transport Policy Institute, Victoria CA, U.S.A.

May, A.D.; Page, M.; Hull, A. 2008. Developing a set of decision-support tools for sustainable urban transport in the UK, *Transport Policy*, 15: 328-340.

Torok, A. 2013. Simplification of road transport infrastructure layout for better self-explanation, *American Journal of Vehicle Design*, 1(1): 16-20.

BUS RIDERSHIP ANALYSIS IN AMMAN CITY

Mohammed Taleb Obaidat[1], Randa Oqab Mujalli[2]
[1] *Department of Civil Engineering, Jordan University of Science and Technology, Irbid (3030), Jordan*
[2] *Department of Civil Engineering, The Hashemite University, Zarqa (13115), Jordan*

Abstract: This study is aimed at analyzing public transportation system within the urban area in Amman, the capital city of Jordan. Amman is having increased growth in population and private auto ownership resulting in congestion which is becoming one of the most frustrating daily problems encountered by most commuters. This increased growth n both population and auto ownership is accompanied with a stigma that is commonly attached to public transit users, in which most commuters prefer to use other modes of transportation in their daily trips. This research work investigated public bus system in Amman City in order to search for the factors that have impact on bus ridership. A survey was collected from 1532 respondents in Amman City in order to find the most important factors affecting the choice of mode of transportation among commuters. Binary logistic regression model was used to model the ridership of bus users. Results of this research work indicated that bus ridership is significantly affected by work trips, income, and private vehicle ownership. It was found that the main riders of public transport users are those whose trip purpose is work, families with low monthly income and those with no private vehicles owned.

Keywords: bus ridership, logistic regression, Middle East, survey.

1. Introduction

Mobility is an essential requirement for any type of meaningful involvement in our modern society. Without some form of adequate transportation, it would not be possible for individuals to shop, to socialize, to work, to worship, or to participate in many other activities (Hough et al. 2002). Moreover, over the last two decades there has been an increased concern with the decline in air quality, increased congestion, and negative impacts to the environment resulting from patterns that are favorable to the automobile (Badoe and Miller, 1999). As a result, improving urban transit services in ways that increase the competitiveness of transit relative to the private automobile and which reduce the growth in car dependence are desirable.

Developing countries in general experience a continuous change in the frameworks in which the urban transport sector exists, and often change rapidly. One of the reasons for this change is because society itself is changing. In other cases, it is because a framework is lacking or contains inherent weaknesses that need to be adjusted (Finn 2011).

Jordan sets an example for framework change where the Land Transport Regulatory Commission (LTRC) of the national Ministry of Transport controls, manage and regulate all land transport services throughout the country. Due to a conflict between Municipality of Amman and Ministry of Transport, in 2007, all responsibility for urban passenger transport in Amman, including the regulatory role, was transferred to Greater Amman Municipality while LTRC continues to regulate services elsewhere in the kingdom.

The culture of public transportation in developing countries, including Jordan, is suffering from different factors that would affect the reputation of its usage. These factors may include mismanagement of transportation facilities, delay and time scheduling, randomness of routes and pathways, undefined bus stops, daily fluctuations of number of buses for every route, lack of planning studies that define important variables to predict number of vehicles required for every zone or route, etc. These factors would make people reluctant to use public transportation; instead they would prefer to own their private vehicles regardless of economical situations.

Limited studies have been performed to evaluate mobility in cities of developing economies, where most of the research found on mobility is done for developed countries and therefore the results obtained cannot be used to evaluate mobility in developed economies, given large differences between them, such as infrastructure, economic conditions and administrative capacities. To this end, this study is aimed at predicting the individual's likelihood to ride buses using logistic regression using socio-economic and travel behavior characteristics.

2. Literature review

Mobility in developing world is affected with many factors that include increased motorization where urban structure is incompatible with the increased motorization, as well as, high demand that exceed capacity of facilities accompanied with increased population, increased wealth, a life style that encourages car ownership, etc (Gakenheimer, 1999).

On the other hand, there is a great need for a more sustainable urban transport for the future because of environmental deterioration, growing energy crisis, and traffic congestion combined with financial constraints. Koushki et al. (1999) tested the transit management awareness of passenger needs due to what have been noticed of a general lack of up-to-date information on the assessment of customer satisfaction with current services and future needs in Kuwait and other Persian Gulf region. In order to determine levels of management awareness of passenger priorities, and passenger satisfaction with the current performance of the bus service, two structured questionnaires were developed; one of these questionnaires was filled by top and middle managers of the transit system; while the other questionnaire was filled by passengers. These questionnaires were performed over a 10-month period; their results indicated that 93% of bus riders

[1] Corresponding author: mobaidat@just.edu.jo

in Kuwait were low income expatriates from 16 different nationalities.
A computer-based phone survey was conducted by De Palma and Picard (2005) in Paris area and suburbs in which 4137 person were questioned in order to study the impact of travel time on route choice for private and/or public transportation commuters and introduced an index that measures the preferences towards risk in choice, also, the impact of key socio-economic factors (gender, employment, purpose of trip, etc.) on the risk of choice were considered, a discussion of three alternative models was performed in order to remove the unrealistic assumption that all users select the shortest route.
Commuters of different occupations differ in their mode choice according to their departure time, hence value of time and work time flexibility differ among different sectors of careers; self-employed workers as well as professionals value their times highly and they have flexible schedules, where employees have rigid work schedules, but have a less value of time; consequently higher incomes enables people to pay out-of-pocket money to avoid inconvenient modes of transportation (Arnott et al. 1994), (Evans, 1992), (Cohen, 1987), (Small, 1983).
Transit ridership modeling is normally performed using either multivariate regression or discrete choice models. Ahmad and Puppim de Oliveira (2016) employed multivariate regression in an attempt to estimate the amount of transport (private and public) using a nationally representative household survey from the 98 largest Indian cities. In addition, they used binary logistic regression to model choices between motorized and non-motorized, and private versus public transport. Findings revealed that densification in Indian cities reduce the amount of transport as well as enhances the probability of using public transport. Small and medium sized cities predominantly use private transport, whereas large cities prefer public transport but lack non-motorized transportation. Moreover, income was found to be the most important determinant of the amount of transport and the use of motorized and private transport.
Abdel-Aty (2001) used an ordered probit model to explain the likelihood of using transit based on a stated preference survey in two metropolitan areas in California. The study investigated whether advanced transit information would increase the acceptance of transit, and to determine the types and levels of information that are desired by commuters. the results indicated that the frequency of service, number of transfers, seat availability, walking time to the transit stop and fare information are among the significant information types that commuters desire. Factors found to contribute to the likelihood of using transit given information was provided were: income, education, and commute time by transit and whether the commuter is currently carpooling.
Al-Shili and Sadeq (2003) presented a study to evaluate intercity ridership demand, evaluate the existing services and predict future ridership in Palestinian territories. An on-board survey of bus riders was conducted to identify variables that influence demand. They used a simple linear regression to model ridership demand using the following variables: population of the origin city, population of destination city, bus fare, and percent of employees at origin city and percent of higher education students at origin city.
Nkurunziza et al. (2012) analyzed individual commuter preferences towards a proposed bus rapid transit system in Dar-es-Salaam, Tanzania. A stated preference survey was conducted in an attempt to identify how commuters perceived and value the proposed service quality variables. They following variables were considered: travel time, travel fare, and comfort; where the results of the survey were analyzed using a binary logit model. The findings revealed that comfort was the most valued variable compared to travel time and travel fare.

3. Data and methodology

3.1. Survey

A survey was conducted among citizens of Amman city in order to find out factors affecting their mode of transportation choice behavior.
Respondents were interviewed on bus stops all over Amman city where 1532 in person interviews were conducted and respondents were asked questions concerning their socio-economic characteristics as well as their travel behavior characteristics. The main purpose of this survey was to study the behavior of commuters especially those of public buses in order to estimate the factors that contribute in bus ridership.
The first part of survey attempts to better understand the individuals and household characteristics such as: gender, age, income, number of family members, type and location of work, number of family members above 18 years, preferred home-based-work travel mode, number of household's automobiles, distance between home and job.
The second part of the survey attempts to better understand the bus commuter's information such as: time to reach a bus stop, trip purpose, and travel time on bus. These questions are the variables of the models to be developed, in which bus ridership is assumed to be a function of variables used in the survey.
Questions concerning origin-destination exact location were excluded, since most of respondents have ignored these questions, Table 1 shows the variables included in the survey as well as the counts and percentages of responses obtained under each category of variables.

3.2. General description of survey answers

According to Table 1 the total interviewed sample had 29.5% females. In addition, 88.7% of interviewed people were above 18 years. Most of the interviewed persons were either employees or university students with percentages of 38.3 for each. Approximately 80% of the surveyed sample ride buses in their daily trips, 45.56% stated that they use buses daily for home-based-work trip. Regarding household size, more than 65% were members of households of six or more. All interviewed individuals reported having at least one family member above 18 years old, 62% of interviewed sample have monthly income below JD 500, while less than 4% earned more than JD 1500 per month. Approximately 40.4% of sample has no autos owned by household, where 38.7% have only one auto owned by household. Regarding distance between home place and work place, 71% of individuals estimated the distance to be more than 3km, while 12% estimated the distance to be in between 2-3km.

Table 1
Variables included in the survey with counts and percentages obtained under each variable

Variable	Categories	Count	Percentage
Place of residence	Don't Live in Amman Live in Amman	310 1222	20.2 79.8
Gender	Female Male	452 1080	29.5 70.5
Age	<18 years ≥18 years	1359 173	88.7 11.3
Job	School University Employee Self employed Unemployed Other	157 587 587 141 27 33	10.2 38.3 38.3 9.20 1.80 2.20
City of Work	Amman Outside Amman	217 1315	14.2 85.8

Table 1
Continued

Variable	Categories	Count	Percentage
Work trip mode of transportation	Bus Shared cab Taxi Automobile Carpooling Work private vehicle other	698 157 136 289 34 162 56	45.6 10.2 8.90 18.9 2.20 10.6 3.70
Family members plus respondent	Alone 1 2 3 4 5 6 7 >7	86 25 81 143 199 269 230 258 241	5.60 1.60 5.30 9.30 13.0 17.6 15.0 16.8 15.7
Family members >18 years	1 2 3 4 5 6 7 >7	263 344 303 277 169 94 78 54	17.2 22.5 19.8 18.1 11.0 6.10 5.10 3.50
Monthly household income, JD	<300 300-499 500-749 750-999 1000-1500 >1500	430 522 256 111 153 60	28.1 34.1 16.7 7.20 10.0 3.90
Number of autos owned by household	0 1 2 3	619 593 231 56	40.4 38.7 15.1 3.70

	>3	33	2.20
Home-based-work trip distance, km	<0.5 0.5-1 1-2 2-3 >3	85 83 87 188 1089	5.50 5.40 5.70 12.3 71.1
Ridership of public buses daily	Don't ride Ride	303 1229	19.8 80.2
Time to access bus stop, min	<10 10-15 15-30 >30	404 277 281 267	26.4 18.1 18.3 17.4
Bus trip purpose	School University Work Shopping Transfer to other mode Other	107 411 397 115 163 36	7.00 26.8 25.9 7.50 10.6 2.30
In bus trip length, min	30-44 45-59 >60	400 255 184	26.1 16.6 12.0

In the second part of the survey, those using buses in their daily trips were asked to give their answers. 26.4% estimated the time to reach the closest bus stop to be less than 10 minutes, while 17.4% answered as belonging to the category of more than 30 minutes. Bus was used in 26.8% of daily trips to university, where 26% used buses in their daily Home-Based-Work trips. Travel time by bus was estimated by 25.5% of individuals to be less than 30 minutes, and about 12% estimated the travel time by bus to be more than 60 minutes.

3.3. Binary logistic regression

The variables' data from the survey was analyzed using a random utility model. This type of models is considered the most used model for processing data from choice experiments in transportation research (Ben-Akiva and Lerman 1985; Louviere et al.2000). The assumptions made by the model are that travel decision makers encounter a utility maximization problem based on the cost and quality of service rising from using a given mode and the uncertainty of choosing the given mode (Ortuzar and Willumsen 1994).

In this research; the response variable, bus ridership, is a binary variable and the independent variables are categorical, and hence the logistic regression is a suitable technique to be used. Table 2 includes a detailed description of the statistically significant variables incorporated in the statistical analysis.

Binary logistic regression is a type of generalized linear models (GLM), which models how a binary response is dependent on a set of explanatory variables. The explanatory variables can be discrete, continuous or a combination (Shafique and Hato, 2015).

Consider these factors or explanatory variables be represented by $X=(X_1, X_2, \ldots, X_k)$ with observed value $xi=(x_{i1}, x_{i2}, \ldots, x_{ik})$ for a survey respondent. Let Y be the binary response variable where $Y_i=1$ if the respondent rides bus and $Y_i=0$ if otherwise. The probability (π) that the person ***i*** is a bus rider can be formulated as follows:

$$\pi_i = Pr(Y_i = 1|X_i = x_i) = \frac{exp(\beta_0 + \beta_i x_i)}{1 + exp(\beta_0 + \beta_i x_i)}$$

Or

$$logit(\pi_i) = log\left(\frac{\pi_i}{1-\pi_i}\right)$$
$$= \beta_0 + \beta_i x_i$$
$$= \beta_0 + \beta_1 x_{i1} + \cdots + \beta_k x_{ik}$$

4. Results and analysis

4.1. Variables and cross tabulations

In this research, we use cross tabulation and binary logistic statistical model based on the survey data to determine the various variables influencing passengers' willingness to use the bus service as described by the dependent variable bus ridership.

Table 2
Variables used in model, their Symbols, categories and coding

Variable	Symbol	Categories	Coding
Ridership of public buses daily	Y	Don't ride* Ride	0 1
Place of residence	X_1	Don't Live in Amman* Live in Amman	0 1
Gender	X2	Female* Male	0 1
Age	X3	≥18 years* <18 years	0 1

Table 2
Continued

Variable	Symbol	Categories	Coding
Job	X4	School University Employee Self employed Unemployed Other*	X4 X4-1 X4-2 X4-3 X4-4 X4-5
City of Work	X5	Amman Outside Amman*	1 0
Work trip mode of transportation	X6	Bus Shared cab Taxi Automobile Carpooling Work private vehicle Other*	X6 X6-1 X6-2 X6-3 X6-4 X6-5 X6-6
Family members plus respondent	X7	Alone 1 2 3 4 5 6 7 >7*	X7 X7-1 X7-2 X7-3 X7-4 X7-5 X7-6 X7-7 X7-8
Family members >18 years	X8	1 2 3 4 5 6 7 >7*	X8 X8-1 X8-2 X8-3 X8-4 X8-5 X8-6 X8-7
Monthly household income, JD	X9	<300 300-499 500-749	X9 X9-1 X9-2

		750-999 1000-1500 >1500*	X9-3 X9-4 X9-5
Number of autos owned by household	X10	0 1 2 3 >3*	X10 X10-1 X10-2 X10-3 X10-4
Home-based-work trip distance, km	X11	<0.5 0.5-1 1-2 2-3 >3*	X11 X11-1 X11-2 X11-3 X11-4

Cross tabulation was used to analyze the responses of the respondents whether they use buses in their daily trips or not in order to find out the differences between these two groups as shown in Table 3. Respondents were divided into two groups: bus riders and not bus riders, where the interviewed sample had 80.2% of bus riders and the remaining 19.8% of not bus riders. As illustrated in Table 3, both groups do not differ in the fact that most of the riders belong to ages above 18 years old, where university students and employees were the categories that ride buses on a daily basis with percentages of 41.33% and 34.50% respectively, while the employees was the category with highest percentage of riding other modes of transportation with a percentage of 53.80% in the not bus rider group.

Regarding gender of riders, it can be seen in both groups that the majority of riders are males with percentages of 70.38% in bus riders group and 70.96% in not bus riders group, with a small higher percentage of females in the bus riders group.

Most of the respondents work in Amman with a higher percentage of bus riders who use the bus from outside Amman workers. The highest percentage of bus riders belong to families with 6 members, while an unexpected result was found in the not bus riders group were most of the respondents belong to families of 7 and more than 7 family sizes. Most of the respondents belonging to either group came from families with 2 members above 18 with percentage of 21.97% for bus riders, and 24.42% for not bus riders. As expected, most of the bus rider have monthly income below JD 500, while most of the not bus riders have monthly between JD 1000-1500. Regarding number of autos owned by household, most of the bus riders group has at most 1 auto, while those belonging to not bus riders have mostly 1 or 2 autos owned. Finally, most of the respondents in the two groups have their daily work trips for distances longer than 3 km.

Table 3
Cross tabulations of survey responses related to bus ridership

Variable	Categories	Ride bus, %	Don’t ride, %
Gender	Female Male	26.62 70.38	29.04 70.96
Age	≥18 years <18 years	97.69 2.31	86.49 13.51
Job	School University Employee Self employed Unemployed Other	12.04 41.33 34.50 8.62 1.55 1.96	2.97 26.07 53.80 11.55 2.64 2.97
City of Work	Amman Outside Amman	84.05 15.95	93.07 6.93
Family members plus respondent	Alone 1 2 3 4 5 6 7 >7	6.83 1.55 5.94 10.17 14.00 21.00 17.01 12.69 11.07	0.66 1.98 2.64 5.94 8.91 4.62 6.93 33.66 34.65

Family members >18 years	1	19.93	5.94
	2	21.97	24.42
	3	18.80	23.76
	4	13.75	19.14
	5	11.15	10.56
	6	5.78	7.59
	7	4.72	6.60
	>7	3.91	1.98
Monthly household income, JD	<300	34.17	3.30
	300-499	40.11	9.57
	500-749	15.79	20.46
	750-999	4.96	16.50
	1000-1500	3.82	34.98
	>1500*	1.14	15.18
Number of autos owned by household	0	48.33	8.52
	1	36.78	46.53
	2	10.50	33.66
	3	2.93	6.60
	>3*	1.46	4.95
Home-based-work trip distance, km	<0.5	6.92	0.00
	0.5-1	5.70	3.30
	1-2	5.70	5.61
	2-3	14.48	3.30
	>3*	67.21	86.80

4.2. Bus ridership

The collected data from the 1532 surveys was divided into two samples: a training sample which is used to train the model and a testing sample which is to validate the model developed using the training sample. The results are summarized in the following sections.

4.2.1. Modeling of bus ridership

Seven hundred and sixty six survey data was used to develop a binary logistic model in order to predict ridership of buses. SPSS v.21 was used for model development and analysis; the results of the best model obtained are described herein.
As shown in Table 4, the omnibus tests of model Coefficients table gives the result of the Likelihood Ratio (LR) test which indicates that the inclusion of these variables contributes significantly to the developed model fit. A p-value (sig) of less than 0.05 for the model means that the model is a significant improvement to a model with a constant only.

Table 4
Omnibus tests of model coefficients

Chi-Square	Degrees of freedom (df)	Sig
372.615	8	0.000

From Table 5, we can conclude that 66.8% of variation in bus ridership can be explained by the model developed, where the correct classification rate obtained using this model is 93%.
The p-values are all below 0.05 which means that all included variables in the model are significant. The model results indicates that using a bus for work trips (X_6) increases the odds of riding a bus by 585.688 times more than other going to work using other modes of transportation. The results obtained indicate that riding a bus for work trips is the most important variable in the bus ridership model.
The second most important variable that was found to affect bus ridership and hence increases the likelihood of an individual to use bus service is when the family does not own an automobile (X_{10}) with 39.169 times to more likely ride a bus than families that own more than 3 automobiles. A less effect on ridership was found when the monthly income is between JD 500-749 (X_{9_2}) and when the monthly income is below JD 300 (X_9), with 11.693 and 10.268 times respectively more likely to use a bus than families with a monthly income of more than JD 1500.
The variables with the lowest contribution to bus ridership were in order of importance: when the number of family members was 5 (X_{7_5}) and 6 (X_{7_6}); when the individual uses his/her automobile for work trip (X_{6_5}); or when the individual uses a Taxi for work trip (X_{6_2}) with the following odds ratio respectively: 5.962, 4.469, 4.276, and 3.788.
To this end, variables that have the most significant effect on bus ridership were: daily work trip is by bus, families with no automobiles owned and monthly income below JD 749. Etminani-Ghasrodashti and Ardeshiri (2015) found that individuals lifestyle which includes leisure activities such as going to a club for exercise, strolling in malls and

shopping centers for fun or going to natural gardens, due to the long distances, increases the likelihood of doing them by private car which is in accordance with findings herein, where daily work trips were found to increase the likelihood of riding a bus. In addition Taylor, et al (2009) also found that employment affects bus ridership.
Taylor, et al (2009) found that amongst other variables that car ownership was found to affect bus ridership which supports the findings found herein in which it was found that families with no vehicle owned increased the likelihood of bus ridership.
Moreover, results herein indicated that low income increases the likelihood of riding the bus; previous studies also reported the same result as found by Shaaban and Khalil (2013), Taylor, et al (2009) and Mujalli (2007).

Table 5
Model used for predicting bus ridership

Predictor variable	Coefficient	S.E	P-value	Exp (B)	95% C.I. for EXP (B)	
					Lower	Lower
Constant	-2.586	0.383	0.000	0.077		
X_6	6.373	1.059	0.000	585.688	73.455	4669.914
X_{6_2}	1.332	0.490	0.007	3.788	1.449	9.903
X_{6_5}	1.453	0.494	0.003	4.276	1.632	11.266
X_{7_5}	1.785	0.509	0.000	5.962	2.199	16.165
X_{7_6}	1.497	0.489	0.002	4.469	1.715	11.645
X_9	2.329	0.478	0.000	10.268	4.021	26.220
X_{9_2}	2.459	0.435	0.000	11.693	4.989	27.407
X_{10}	3.668	0.414	0.000	39.169	17.385	88.246
-2 Log likelihood	285.632					
Nagelkerke R2	66.8%					
Classification rate	93.1%					

4.2.2. Validation of prediction error rate

The reliability of the prediction error rate observed in the training sample was examined by applying the chosen prediction rule to a validation sample as illustrated in Table 6. The new prediction error rate is about the same as that for the training data set, then the latter gives a reliable indication of the predictive ability of the fitted binary logistic regression model and the chosen prediction rule.
In the current study, the fitted logistic response function based on the training sample given in Table 5 was used to calculate the estimated probabilities for the 766 cases of validation sample. The chosen prediction rule is applied to the estimated probabilities as predict 1 if $\pi_i \geq 0.5$ and predict 0 if $\pi_i < 0.5$. The percent prediction error rate for the validation sample given in Table 6 is 85.6 while the rate for the training sample was 93.1. Thus the total prediction error rate for the validation sample is not considerably higher than the training sample and it can be concluded that it is a reliable indicator of the predictive capability of the fitted logistic regression model.

Table 6
Predicted classification table based on training sample and validation sample taking 0.5 as cutoff

Training sample				Validation sample			
Observed (Y)	Expected (Y)			Observed (Y)	Expected (Y)		
	0	1	% correct		0	1	% correct
Do not Ride bus (0)	90	28	76.3	Do not Ride bus (0)	150	35	81.1
Ride bus (1)	25	623	96.1	Ride Bus(1)	75	506	87.1
Overall percentage			93.1	Overall percentage			85.6

5. Conclusions

The main objectives of this research work were to find out the factors that have the most significant effect on bus ridership in Amman City using socio-economic and travel behavior characteristics. Work trips commuted by bus were found to have the highest positive impact on bus ridership. It was also found that the bus riders are more likely to be those belonging to families with low-income, which has created a poor local image of the service and driven other population categories away from using the service. In addition, low vehicle ownership was found to increase the probability of riding buses.
In order to encourage public buses riding, public buses need to be improved in order to compete with other modes of travel such as private cars and taxis. Emphasis on improving the image of buses should be a priority.

References

Abdel-Aty, M.A. 2001. Using ordered probit modeling to study the effect of ATIS on transit ridership, *Transport. Res. Part C: Emerg. Technol*, 9(4): 265-277.

Ahmad, S.; Puppim de Oliveira, J.A. 2016. Determinants of urban mobility in India: Lessons for promoting sustainable and inclusive urban transportation in developing countries, *Transport Policy*.

Al-Shili, K.; Sadeq, A. 2003. Ridership Demand Analysis for Palestinian Intercity Public Transport, *Journal • of • Public • Transportation*, 6(2): 19-35.

Arnott, R.; de Palma, A.; Lidesy, R. 1994. The Welfare Effects of Congestion Tolls with Heterogeneous Commuters, *Journal of Transport Economics and Policy,* 28: 139-161.

Badoe, D.A.; Miller, E.J. 1999. Transportation-Land –Use Interaction: Empirical Findings in North America and their Implications for Modelling, *Transportation Research Part D*, 5: 235-263.

Ben-Akiva, M.; Lerman, S.R.1985. *Discrete Choice Analysis: Theory and Application to Travel Demand*. Cambridge, Massachussets: The MIT Press.

Cohen, Y. 1987. Commuter Welfare Under Peak-Period Congestion Tolls: Who gains and Who Looses?, *International Journal of Transport Economics*, 14: 239-266.

De Palma, A.; Picard, N. 2005. Route Decision under Travel Time Uncertainty, *Transportation Research Part A,* 39: 295-324.

Etminani-Ghasrodashti, R.; Ardeshiri, M. 2015. Modeling travel behavior by the structural relationships between lifestyle, built environment and non-working trips, *Transportation Research Part A*, 506-518.

Evans, A.W. 1992. Road Congestion Pricing: When is it a Good Policy?, *Journal of Transport Economics and Policy,* 26: 213-243.

Finn, B. 2011. Urban bus services in developing countries and countries in transition:a framework for regulatory and institutional developments, *Journal of Public Transportation*, 89-107.

Gakenheimer, R. 1999. Urban Mobility in the developing World, *Transportation Research Part A*, 33: 671-689.

Hough, J.A.; Bahe, C.; Murphy, M.L.; Swenson, J. 2002. Intelligent Transportation Systems: Helping Public Transit Support Welfare to Work initiatives. Available from Internet: <http://ntl.bts.gov/lib/13000/13100/13140/>.

Koushki, P.A.; Al-Saleh, O.I.; Al-Lumaia, M. 2003. On Management’s Awareness of Transit Passenger Need, *Transport Policy*, 10: 17-26.

Louviere, J.J.; Hensher, D.A.; Swait, J. 2000. *Stated Choice Methods: Analysis and Application*. Cambridge: Cambridge University Press.

Mujalli, R.O. 2007. Spatial Analysis of Public Transportation- Case Study: Amman- Jordan, M.S. thesis, Jordan University of Science and Technology, Irbid, Jordan.

Nkurunziza, A.; Zuidgeest, M.; Brussel, M. 2012. Modeling Commuter Preferences for the Proposed Bus Rapid Transit in Dar-es-Salaam, *Journal of Public Transportation*, 15(2): 95-116.

Ortuzar, J.D.; Willumsen, L.G. 1994. *Modelling Transport*. Chester, UK: John Wiley & Sons.

Shaaban, K.; Khalil, R.F. 2013. Investigating the customer satisfaction of the bus service in Qatar, *Procedia-Social and Behavioral Sciences*, 104: 865-874.

Shafique, M.A.; Hato, E. 2015. Modelling of acceporemeter data for travel mode detection by hierarchical application of binomial logistic regression, *Transportation Research Procedia*, 10: 236-244.

Small, K.A. 1983. The Incidence of Congestion Tolls on/urban Highways, *Journal of Urban Economics*, 13: 90-111.

Taylor, B.D.; Miller, D.; Iseki, H.; Fink, C. 2009. Nature and/or nurture? Analyzing the determinants of transit ridership across US urbanized areas, *Transportation Research Part A*, 60-77.

Truong, L.; Somenahalli, S. 2015. Exploring frequency of public transport use among older adults: A study in Adelaide, Australia, *Travel Behaviour and Society*, 2: 148-155.

SESSION 11: ROAD TRAFFIC AND TRANSPORT RESEARCH - SAFETY PERSPECTIVE

THE CARGO SECURING BASED ON EUROPEAN STANDARDS AND ITS APPLICABILITY IN OFF-ROAD TRANSPORT CONDITIONS

Martin Vlkovský[1], Kateřina Pochobradská[2], Pavel Foltin[3], Václav Zajíček[4], Tomáš Binar[5]
[1,2,3,4,5] University of Defence, Czech Republic

Abstract: The cargo is secured with respect to inertial forces in the Czech Republic, which are based on the anticipated acceleration coefficients specified in relevant European standards (particularly in EN 12195-1:2011). The paper deals with the evaluation of a sample of off-road transportation, for which the true values of acceleration coefficients were found. The data are statistically processed; the local extremes of functions are found and compared with the average values of acceleration coefficients defined normatively. The paper was written with the support of research project no. SV16-FVL-109-VLK funded by the Ministry of Education, Youth and Sports. The fundamental goal of this research project is to determine whether the differences between the acceleration coefficients defined normatively and true value of these coefficients are statistically significant and based on that to optimize the cargo securing. Preliminary measurements detected that especially during off-road transport, or due to specific obstacles (e.g. railway crossings, speed bumps, expansion joints of bridges, holes and potholes on the roads), the acceleration coefficients are significantly higher. The model example demonstrates the importance of the measured differences in the cargo securing with using the lashing straps.

Keywords: off-road transport, cargo security, inertial forces, acceleration coefficients.

1. Introduction

In civilian sector transport accounts for about 60-70 % of logistic activities. In the Army of the Czech Republic (ACR) it is estimated that the percentage corresponds with the civilian sector. A major difference in the implementation of the transport; physical relocation of cargo (or persons); is the fact that transportation in the ACR are often carried out under different conditions. This applies especially during realization of Intra-Theater Transport, which uses mainly road transport. This paper focuses on road transport under specific conditions, especially outside of normal communication or off-road.

Each cargo must be secured against movement and the mounting is based on norms, standards or internal regulations, which further regulate mentioned norms and standards. In Europe is generally used standard EN 12195-1:2011, which (among other things) mentions the coefficients of acceleration in particular axes and formulas for calculating the various mounting methods. Mentioned coefficients of acceleration are stated empirically (outcomes of empirical studies) and stated in **average values**.

Preliminary analysis and experiments (see eg. Vlkovský et al., Crede Expert, 2016) so far showed short-term shocks – fluctuations above commonly mentioned (averaged) values determined normatively, especially in the z-axis. The paper is based on the assumption that non-standard conditions of transport – terrain will cause even greater fluctuations in the z-axis (or the other two axes). Significant for mounting method are the values that significantly exceed the normative set values (eg. 100 % or more). Standard EN 12195-1: 2011 mentions values of the coefficients of acceleration in particular axes (c_x, c_y and c_z) in the interval *0.5* to *1.0 g*, where g is the gravity acceleration (EN 12195-1, 2011).

For illustration if the cargo is mounted with respect to the anticipated effect of inertial forces when the individual acceleration coefficients are maximum *1.0 g*, then the mounting with values for example *2.0 g* is totally insufficient. One-ton cargo in such cases, "behaves" like a two-ton and mounting agent is thus doubly burdened than assumed in accordance with normative established values of the acceleration coefficients and formulas for determining the value of inertial forces.

Application of such research suggests itself primarily in military conditions (especially in multinational operations) and in the integrated rescue system, respectively other entities which execute transportation (generally) outside of normal communication. Specific with even higher risk is transport of dangerous goods in off-road conditions.

2. Transportation experiment

The object of the transport experiment is to prove on a sample data set imperfection of normative established acceleration coefficient values, including their averaging. For statistical analysis a survey is carried out on a sample of drivers during **Advanced Training in Military Vehicles Driving**, which took place on 1st June 2016 in the training area Vyškov-Dědice in the Czech Republic, from 8:37 to 11:43 a.m. The weather on that day was standard for June, the surface was dry, visibility was excellent, and there were no rainfalls during training. Selected vehicle was equipped with an accelerometer – tri-axial shock data logger OM-CP-ULTRASHOCK-5 serial number P93709 which recorded acceleration (shock) in multiples of *g* in all three axes. Recording was done at frequency of 512 Hz, when the highest, respectively the lowest value of the given axis is recorded into the data logger every second (Jakar Electronics, 2016).

[1] Corresponding author: martin.vlkovsky@unob.cz

2.1. Background of the transportation experiment

A relatively new type of truck – Tatra T-810 DO AŠ which is used in ACR was chosen for statistical evaluation. Used vehicle was in very good technical condition with relatively small mileage (34,000 km). Part of the vehicle was cargo – simulated cargo of 2,160 kg (01-0601-CZE/00, 2007).
The training was conducted at the polygon marked in green color (see Fig. 1) where the drivers according to schedule took turns; one went the route there and the second one went the route back (sectors 1 and 2 on the chart – see Fig. 2); respectively each of them went the route there and back (sectors 3-7 – ibid). The polygon is composed of stones and bricks embedded in concrete – it is a normal transport route in the training area Vyškov-Dědice. Terrain to a certain extent simulates conditions in multinational operations in countries with limited transport infrastructure, where except the backbone roads the transport network consists from only partially metalled or non metalled roads.
The aim of the training was to improve driving of selected vehicles, in this case the Tatra T-810 DO AŠ under the supervision of an experienced instructor – professional driver. Part of the training with the given type of vehicle was not overcoming obstacles, etc., as it was in the case of other types of vehicles at the same training day. Transport conditions at the polygon were therefore in terms of road (terrain relief) relatively homogeneous.
The total number of drivers was 14 + 1 professional driver who always moved the vehicle along the red route for interchange of drivers at the polygon. Mentioned (red) route back was realized by professional driver himself – see the sections of the route in red rectangles on the graph in Fig. 2. Transports with two drivers in one direction only were implemented in sections 1 and 2. That means the first from the pair launched a transport at the conversion of red and green section (after handover to the professional driver) and drove the end of green route, where the truck turned (using reversing) and handed control to the second driver from the pair. In the remaining sections with regard to plenitude of time each of transport of drivers in training was realized through the entire polygon, that means back and forth, including a turn at the end of the polygon.

Fig. 1.
Testing polygon (green), route for translocation (red)
Source: (Google Maps – modified)

2.2. Statistical evaluation of the transportation experiment – *z*-axis

It is obvious from the data that the acceleration in each axis is significantly influenced by driving style of the driver and by speed. Individual drivers can be compared with each other, respectively with professional driver. The differences are

mainly caused by different experiences of drivers, because some of them have much less experience with the given type of vehicle than others (eg. difference between 5th and 6th sector) and driving style.
Road roughness significantly affect primarily z-axis which according to the standard should be within the interval *<–1,1>*. In the graph it corresponds with values of *0-2g* as an imaginary zero of the graph corresponds with *1g*. However the graph shows that big amount of data, *1,631* values (*18.66 %* of the total, with no vehicle standstill – see below) measured in the z-axis exceeds *2g*, which corresponds to the normative given limit *1g*. In further *53* cases (corresponding to *0.61 %* of the total, with no vehicle standstill) the values of the given axis even exceed the limit of *3g*, which reflects the double overrun of normative set values (specifically *2g*). In this case cargo during transport "behaves" as though it had twice the mass – the value of inertial force F_z (ceteris paribus) is twofold. By analogy arithmetic mean of the values in the z-axis can be mentioned: $\mu_z = 1.76g$; median: $Me_z = 1.74g$ and the most common value (modus): $Mod_z = 1.69g$. Mentioned statistical values show that according to statistical evaluation they fall within the normative specified interval (in the graph in Fig. 2 into the already mentioned *0-2g*). Standard deviation is: $\sigma = 0.37$.
Interesting is also the kurtosis, which indicates the occurrence of very low and very high values (extremes) $\gamma_{2z} = 26.38$. To be complete skewness is near zero $\gamma_{1z} = -0.22$, then a distribution almost corresponds with standardized normal distribution. For the "negative" shock any relevant data with the exception of two rare variations were not measured. Sporadic variations; which are not statistically seizable; shown in the seventh section of the z-axis value of over *4g* (resp. over *3g*), respectively almost *–6g* (corresponding to almost *–7g* relative to the subtraction of scale from *1g*) and in the third section the value of *5g* (resp. over *4g*). Variations in the other axes also correspond with mentioned extremes. Although the data does not have great importance to statistics, it can be stated that such a short-term shock; only one is often sufficient during transport; may cause release or even damage (rupture) of the appropriate fixative (eg. textile mounting belt that is most often used for this type of vehicles). For the greatest shock in the z-axis which has been measured takes effect *2,160 kg* inertia force on the cargo which corresponds with the formula:

$$F_z = m \cdot c_z \cdot g \qquad [N]$$

where F_z is the value of the inertial forces in the z-axis, m is the cargo weight, c_z is the acceleration coefficient in the z-axis, and g is the gravitational acceleration that corresponds to the latitude of the Czech Republic $g = 9.81\ ms^{-2}$. The resulting value of the inertial forces is, after introducing the highest measured value from the Table 1, as follows:

$$F_z = 2{,}160 \cdot 6.75 \cdot 9.81 \qquad [N]$$
$$F_z = 143{,}030\ N$$

Based on the calculation simple conclusion can be made the value of the inertial forces in the z-axis is *6.75* times greater than what can be calculated using normative given values c_z. For the particular mounting method entire calculation is additionally affected with additional input data: acceleration coefficients in the other axes, angles formed by the mounting belts, the dynamic coefficients of friction, etc. This fact would lead even to deterioration of the resultant straining of mounting mean in comparison with the simple calculations using Newton's second law of motion.

Table 1
The biggest measured variations in particular axis (grey cells) and comparison with other axes

Date	Time	*x*-Axis (g)	*y*-Axis (g)	*z*-Axis (g)
2016-06-01	11:18:52	5.50	–1.74	–6.75 (–5.75)
2016-06-01	09:24:19	3.40	–2.28	5.35

Note: For z-axis data logger (akcelerometr) measured value of –5.75g, however the value is indicated not from zero but from value of 1g.
Source: (Own)

From Fig. 1 also results that under the given conditions (for a given polygon) extreme variations in one axis are usually accompanied by large fluctuations in other axes. For the x-axis and z-axis is the time of the greatest (for x-axis), respectively the smallest (z-axis) variation the same – see the first line of the table.

2.3. Statistical evaluation of the transportation experiment – *x*- and *y*-axis

The statistical evaluation is not so attractive for the other two axes as for the z-axis. Values of statistical quantities are, with few exceptions, less significant than for the z-axis. Acceleration coefficients are according to the standard set on $c_x = 0.8$ and $c_y = 0.6$.
From the point of view of statistical quantities the values are normal: $\mu_x = 0.06g$, resp. $\mu_y = 0.05g$ (arithmetic mean), $Me_x = 0.19g$, resp. $Me_y = 0.21g$ (median) a $Mod_x = 0.42g$, resp. $Mod_y = 0.25g$ (modus). Standard deviation is in case of x-axis bigger than for z-axis: $\sigma_x = 0.46$, resp. $\sigma_y = 0.32$. Kurtosis is also less important: $\gamma_{2x} = 5.40$, resp. $\gamma_{2y} = 2.29$. Skewness is completely unimportant, by analogy same as for z-axis: $\gamma_{1x} = -0.01$, resp. $\gamma_{1y} = -0.32$.

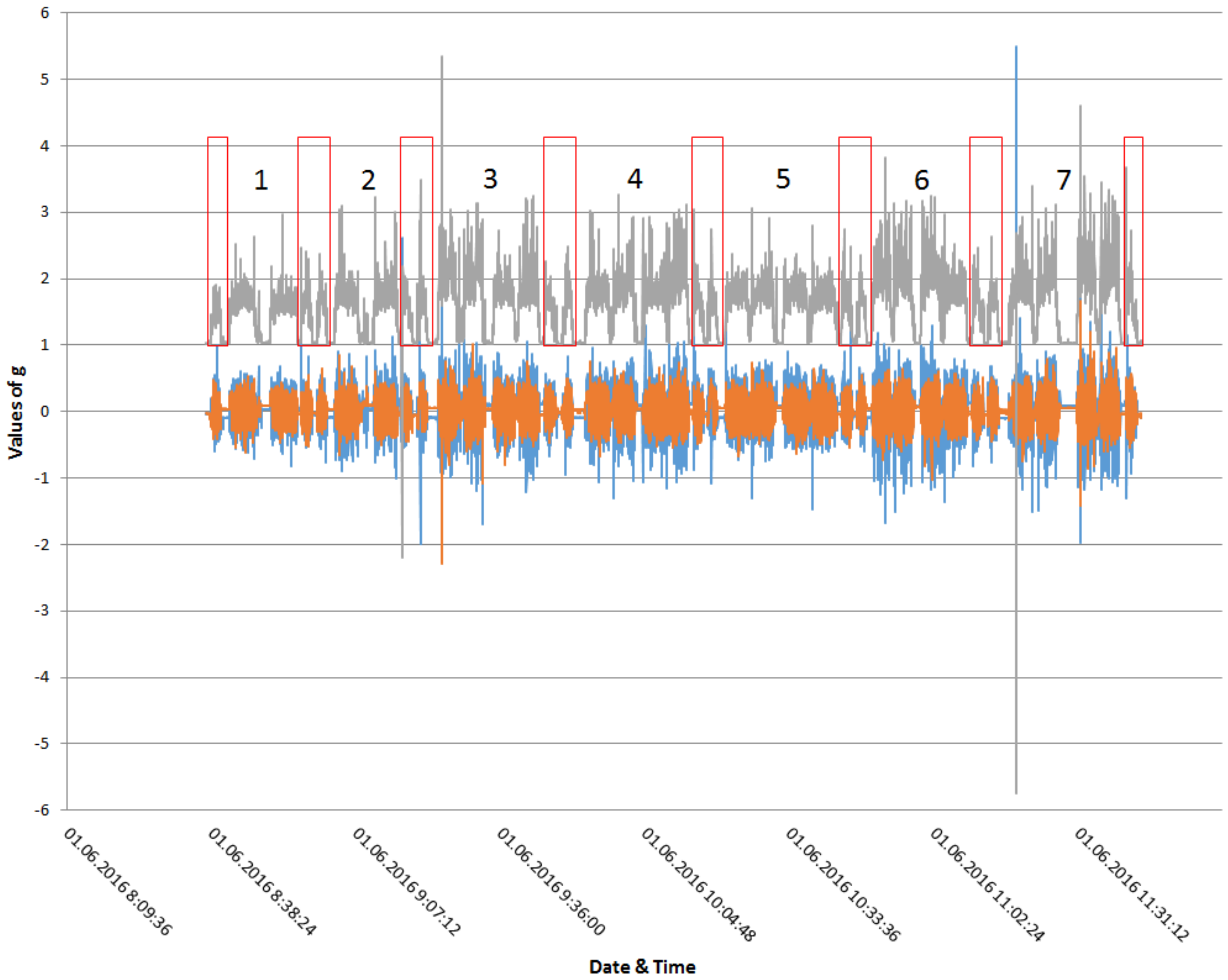


Fig. 2.
Graph of the (shock) acceleration in particular axes
Legend:

P93709 - Shock - X Axis (g)
P93709 - Shock - Y Axis (g)
P93709 - Shock - Z Axis (g)

Source: (Own)

3. Conclusion

The benefit of acceleration coefficients determination and their statistical evaluation consist in adjusting the normatively set values for the calculation under specific conditions. Terrain, respectively rocky road in the training area showed significant deviations from the maximum normatively set values, which were determined through empirical studies and data were subsequently statistically processed (averaged). The lack of average values was perceptible for example in z-axis in part 2.2. Although only *0.61 %* of the values from *8,741* (consolidated data, when from the total number of measured values *11.181, 2,440* values represented standing of the truck) crossed the border of *3g* (resp. *2g* related to the initial value of *1g*). However in absolute numbers *53* times release of cargo could happen because the values that are more than double compared to expectations may stand for a significant risk to the cargo.
In accordance with the European Commission – Mobility and Transport (Road Safety) assessment of the weaknesses in cargo mounting includes inappropriate mounting methods or inappropriately selected mounting mean among major or dangerous deficiencies, depending on the particular deficiency (European Commission M & T, 2014). In extreme cases inappropriately chosen method of cargo mounting can cause damage to human health, whether drivers or loading/unloading group.
In further research there is an assumption to compare larger sample of data under comparable conditions and also perform data collection in very specific conditions, such as terrain. A necessary condition is usage of multiple dataloggers on a single vehicle, which will at least partly lead to elimination of sporadic fluctuations in measurements or verification that the fluctuations are not caused by measurement error, but actually influence the cargo.

There is the assumption to compare outputs with simulations and models within the further research, which are based on technical parametres of the vehicle and use e.g. bondgraphs (Gupta, A.; Rastogi, V., 2011 or Gupta, A.; Rastogi, V., 2015), or another type of accelerometers based on MEMS technology with GPS (Sokolovic, V et al., 2015).
With regard to basic research the conclusions may not fully correspond with premises, but preliminary measurements in contrast indicate values greater than originally expected. In other words, the specific conditions of transport (road – terrain) can very negatively influence the cargo and its mounting system. Impact on mounting also depends on the used fixative mean. In the ACR the most often used are different variants of mounting belts which can deform with when overload, fray and even break in extreme cases. Unambiguously we can talk about the negative impact on the mounting belts lifetime which in such conditions cannot be guaranteed and cannot match the lifetime mentioned in the product documentation. A very important fact is also responsibility for any damage of the cargo, which, in such cases, loading group would be held responsible, not the manufacturer, who guarantees lower values of inertial forces (normatively given, averaged).
Transport of the dangerous goods where the pressure to strict adherence to the given mounting ways should be even greater is a particular issue. Presumption for future research is to verify the selected transport of dangerous goods under military conditions (e.g. ammunition, explosives).

Acknowledgements

The paper was written with the support of specific research project no. SV16-FVL-109-VLK: *Optimization of Cargo Securing for Off-road Transportation with Emphasis on Transportation Safety* funded by the Ministry of Education, Youth and Sports.

References

01-0601-CZE/00. *Operator´s Manual for Tatra 810 – 1ROR26 12 177 6×6.1R/321*. TATRA a.s., 1st Edition, 2007.
EN 12195-1. *Load restraining on road vehicles – Safety – Part 1: Calculation of securing forces*. Czech Office for Standards, Metrology and Testing: 2011. 48 p.
European Commission. Mobility & Transport – Road Safety. Available from Internet: <http://ec.europa.eu/transport/road_safety/topics/vehicles/ cargo_securin g_loads/index_en.htm>.
Gupta, A.; Rastogi, V. 2011. Dynamic modeling and Control of off-road truck using Bondgraphs. In *Proceedings of the International Conference on Soft Computing for Problem Solving (SocProS),* 437-450.
Gupta, A.; Rastogi, V. 2015. Effects of Various Road Conditions on Dynamic Behaviour of Heavy Road Vehicle. In *Procedia Engineering of the 12th International Conference on Vibration Problems (ICOVP),* 1129-1137.
JAKAR Electronics, 2016. OM-CP-ULTRASHOCK-5. Available from Internet: <http://www.omegaeng.cz/ppt/pptsc.as p?ref=OM-CP-ULTRASHOCK&Nav>.
Sokolović, V et al. 2015. INS/GPS Navigation System Based on MEMS Technologies, *Journal of Mechanical Engineering,* 61(7-8).
Vlkovský, M.; Pochobradská, K.; Foltin, P. 2016. Off-Road Transport and Cargo Security, *Crede Experto,* 2(9).

OPTIMIZATION OF THE SHAPE OF ROAD SPEED REDUCERS

Francisco Duarte[1], Adelino Ferreira[2], Paulo Fael[3]
[1,2] *Pavement Mechanics Laboratory, CITTA, Department of Civil Engineering, University of Coimbra, Portugal*
[3] *Department of Electromechanical Engineering, University of Beira Interior, Covilhã, Portugal*

Abstract: This paper studies the vehicle-road interaction, in order to determine the most effective characteristics of a speed reducer, to extract the maximum amount of energy from the vehicle, with a minimum impact on it. To study and evaluate this interaction, a computational model was developed and incorporated in ROADVISS, a previously developed software, allowing to define both vehicle and speed reducer parameters, and determining the vehicle oscillations, forces induced on the speed reducer and energy lost, as well as the energy received by the speed reducer. Different surface shapes were considered, with different dimensions, allowing to conclude that the currently used speed reducers shapes are not the most effective. With an appropriate speed reducer shape and dimensions, it is possible to maximize the energy extraction by more than 40%, minimizing the impact on the vehicle in more than 80%, when compared to standard speed reducers.

Keywords: vehicle-road interaction, speed reducer, road safety, simulation software, ROADVISS.

1. Introduction

Road accidents are considered by the World Health Organization (WHO) one of the main problems affecting public health in the WHO European Region, the cause of death of about 120,000 people annually and the leading cause of death in children and young adults aged 5 to 29 years old (WHO, 2010). Additionally, WHO estimates that each year about 2.4 million people are seriously injured as a result of road accidents only in the WHO European Region. Worldwide, estimates that there are about 1.24 million deaths due to road accidents (WHO, 2013).

WHO recommends six strategic points for action in order to reduce effectively and rapidly the number of accidents, especially with vulnerable road users, being the first and more relevant an effective speed reduction.

This issue is of great importance at several levels. Firstly because, as it is properly studied and based on traffic engineering and road safety manuals (Seco *et al.*, 2008; Elvik *et al.*, 2009), the higher the speed, the greater the time and distance for braking and stopping and, consequently, the greater the severity of accidents. The state of the pavement (dry or wet) also has influence on the braking and stopping distances, but the main factor is the vehicle speed at the moment that it begins to brake (Seco *et al.*, 2008). Similarly, it is studied that the probability of an accident involving a pedestrian be fatal is greatly reduced with the reduction of impact speed, being this probability of 80% if the speed is 65 km/h, 45% if the speed is 50 km/h and is lower than 10% if the speed is 30 km/h. These numbers highlight the importance of controlling the speed to keep it below 50 km/h in urban areas and below 30 km/h in residential areas, especially near crosswalks.

Traffic calming measures have emerged as a way to minimize negative impacts of traffic on places where vehicles moves, by moderating their speed, with the main objective being to approach the speed of motorized vehicles to the speed of non-motorized vehicles and/or pedestrians moving in the same space. One of the most effective measures is the change in vertical alignments, especially through the implementation of speed reduction equipment (SRE), as speed bumps. SRE is the traffic calming measure most used globally because it ensures a significant reduction in vehicle speed (Seco *et al.*, 2008; Elvik *et al.*, 2009).

This solution has the advantage of reducing the vehicle speed, not so much in a direct way, with the impact on the vehicle, but indirectly, by forcing drivers to reduce the vehicle speed before hit the equipment, to avoid the impact (Silva, 2010). This equipment increase the respect between vehicles and pedestrians in crosswalks areas and are able to reduce the number of road accidents by 41% (Silva, 2010), although many entities indicating substantially lower values, such as the ITE pointing reductions of 13% (Ewing and Brown, 2010). According to Gifford (2004), this reduction in 20 mph zones (32 km/h) can reach 60%.

Due to the impact of these devices in vehicles and their occupants, such solutions are not suitable for application in crossing roads of locations where the design speed is usually between 40 and 50 km/h (Seco *et al.*, 2008), limiting its range of applications. Another major drawback of SRE is the noise generated by the impact of the vehicle with the equipment, which in residential areas is quite annoying, especially at night (Silva, 2010; Freitas *et al.*, 2013).

From the analysis that was performed, it can be concluded that traffic calming measures presents some effectiveness, yet limited, having margin to be improved and evolved. In the particular case of the SRE, which is presented as the most effective solution in speed reduction, but at the same time presents some restrictions in the possible implementation places, if such solution was optimized and have less invasive characteristics in terms of its impact on vehicles, maintaining the effectiveness in terms of speed reduction, the potential application of these devices would be much greater and their contribution to an effective speed reduction would be higher, allowing a significant decrease in the road accidents rate.

Based on this, the present study intends to overcome an existing gap, by presenting a new approach to reduce road vehicle speed through an innovative SRE, with new characteristics that allows to reduce the impact on vehicles, especially its surface profile, increasing the energy removed to the vehicle and maximizing its speed reduction.

[2] Corresponding author: adelino@dec.uc.pt

Achieving this, it will be possible to implement these devices in places where vehicles move at speeds higher than 40 km/h and reduce their speeds without cause discomfort to their occupants.

2. Standard Speed Reduction Equipment

2.1. Equipment

To improve traffic safety, vehicle speed needs to be reduced in various places, both in and outside urban areas. Three types of measures can be adopted for this purpose: horizontal alignment changes (chicanes, narrows, roundabouts, etc.), vertical alignment changes (humps, platforms, raised crosswalks, etc.), or complementary measures, such as illumination, urban features, among others (Elvik *et al.*, 2009; Ewing and Brown, 2010). The most effective measures to control vehicle speeds are the vertical alignment changes, as these usually affect the vehicle and their occupants, if speed limits are not respected. However, there are some design rules in order to guarantee softness and, therefore, the design speed.

So, SRE should have an impact on vehicles when they travel above the design speed, which causes discomfort to their occupants and, at the same time, should have minimum impact on the vehicles if they travel under the design speed. This is achieved through their geometry and surface profile.

Speed bumps and speed humps built directly in the pavement (with concrete or bituminous mixture) are not considered products in this work, as these are built by the infrastructure manager in accordance with existing standards.

Considering the existing products on the market, mostly speed humps and speed bumps, manufactured with a high-strength rubber (usually vulcanized) with convex or sinusoidal surface profiles, the mostly used products have a maximum height at its center of 3 or 5 cm and widths of 50 or 90 cm, respectively (3M, 2016). The 3 cm height speed bumps are used in places with a speed limit not exceeding 35 km/h, while the 5 cm height are used in places with a speed limit not exceeding 20 km/h.

Some manufacturers have different surface profiles, such as triangular or trapezoidal, maintaining the high strength rubber as the predominant material, using also recycled plastic as the main alternative (TSS, 2016; Hongqiao Traffic, 2016).

There is not an international uniformity regarding the geometric aspects of SRE, including its shape, height, length and width. Considering other research works (Johnson and Nedzesky, 2004; Szurgott *et al.*, 2009), individual countries recommendations (DGV, 2004; Ewing and Brown, 2010) and the previously mentioned products, it can be concluded that the mostly used surface profiles on SRE are, respectively, convex (S1), sinusoidal (S2), trapezoidal (S3) and triangular (S4), being these presented in Figure 1, with L_{max} being the maximum width and h_{max} the maximum height of the surface.

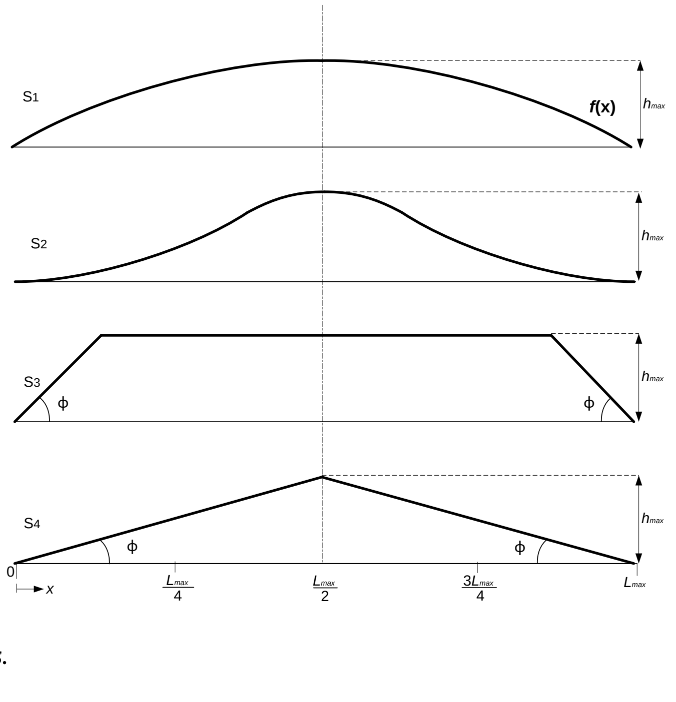


Fig. 1.
Typical SRE surface profiles.

2.2. Vehicle Model and Energetic Analysis

Modeling of four-wheeled vehicles has been studied for the last 50 years. The dynamics and characteristics are well understood and validated models have been developed for many applications, including the study of vehicle vibrations (Gillespie, 1992; Wong, 2001; Blundell and Harty, 2004; Jazar, 2008; Popp *et al.*, 2010; Rajamani, 2011).

To model a vehicle and study the vehicle-road interaction (VRI), the most simple model is the quarter car model, which is the most commonly used and most useful model of a vehicle suspension system (Blundell and Harty, 2004; Jazar, 2008; Popp *et al*., 2010; Rajamani, 2011). This model only represents the sprung mass of the vehicle, the unsprung mass, the suspension system, and the tire, being represented in Figure 2 a). For more complex and detailed studies, regarding only forward linear motion, the most suitable model is the bicycle car model, which is represented in Figure 2 b), and includes the vehicle sprung mass (equal to half of the vehicle), the front unsprung mass, rear unspung mass, front and rear suspension systems, and front and rear tires. The most suitable model to study the interaction between a vehicle and an obstacle in the pavement, as a SRE, is the bicycle car model, being its motion equations defined in the main *Vehicle Dynamics* references (Blundell and Harty, 2004; Jazar, 2008; Rajamani, 2011).

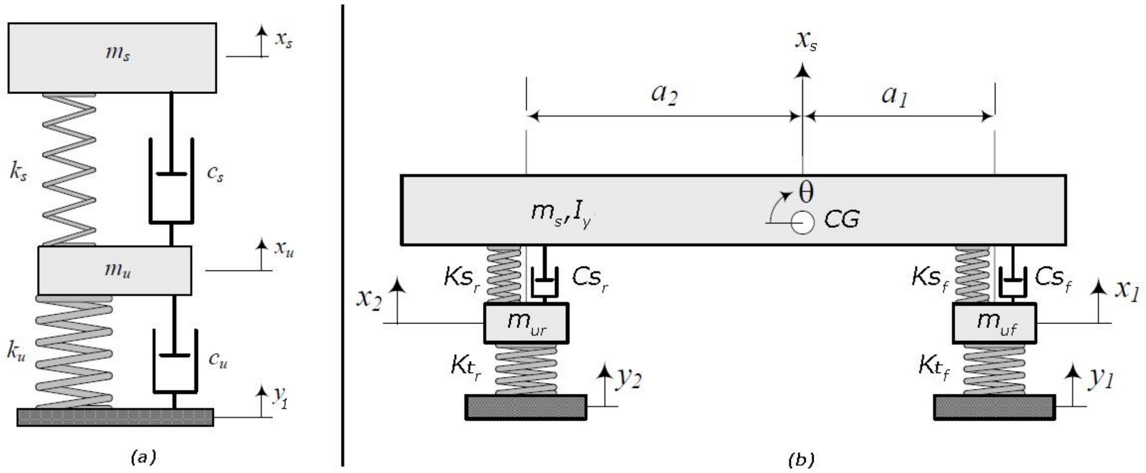


Fig. 2.
(a) Quarter car model and (b) bicycle car model (adapted from Jazar, 2008).

The energy released from the vehicle can be determined using the vehicle speed reduction, which is associated to the lost of kinetic energy (K), using equation (1), with m_v representing the vehicle total mass, v_i the vehicle initial speed and v_f the vehicle final speed, both in m/s.

$$\partial K = \frac{1}{2} m_v \times (\partial v^2) = \frac{1}{2} m_v \left(v_f^2 - v_i^2\right) \quad (1)$$

3. New Speed Reduction Equipment Concept

3.1. Surface profile

The surface profiles represented in Figure 1, typical for standard SRE without surface displacement, have a common feature: its initial and final height is the same, at the road pavement level, so that the vehicle wheel starts and finishes the contact with the equipment at the pavement level.
When the SRE surface has a vertical motion, moving downwards with the force exerted by the moving vehicle wheel, its final height should not be the same as its initial height, so that the vehicle's tire can reach the pavement level immediately after leave the contact with the SRE surface. So, at the surface maximum length, the surface profile height should be the same as the surface maximum displacement. To accomplish this important feature, four different surface profiles were developed, being presented in Figure 3. Each surface profile has the following denomination: *Ramp* (S5), *S Profile* (S6), *Scale Up* (S7) and *Crest* (S8).

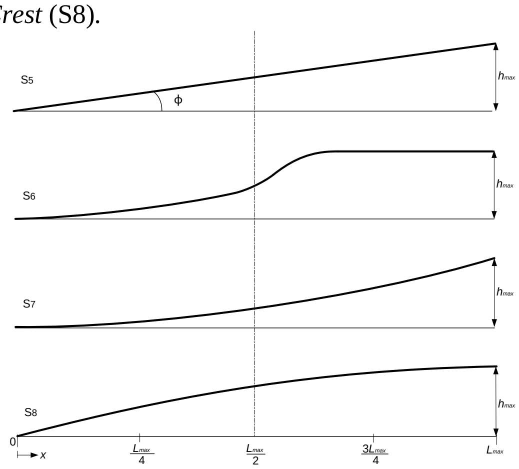


Fig. 3.
New SRE surface profiles for a one degree of freedom movable surface.

3.2. Vehicle Model and Energetic Analysis

The main models to study the VRI were presented in section 2, with special emphasis for the bicycle car model, the most appropriated model to study the interaction between a vehicle and an obstacle in the pavement. Those models were validated for pavements without a movable surface. However, when considering a device with a vertical motion of its surface due to the actuation of the vehicle, the models are incomplete.
The inclusion of a surface with vertical displacement in the pavement for the bicycle car model is represented in Figure 4, being implemented under the equipment surface a one degree of freedom movable system with a displacement x_h, a mass m_h, and a spring with stiffness K_h, responsible for the opposition force to the surface motion, for the mechanical energy storage and for the surface position replacement. The governing differential equations of motion for this model are presented by equations (2-6).

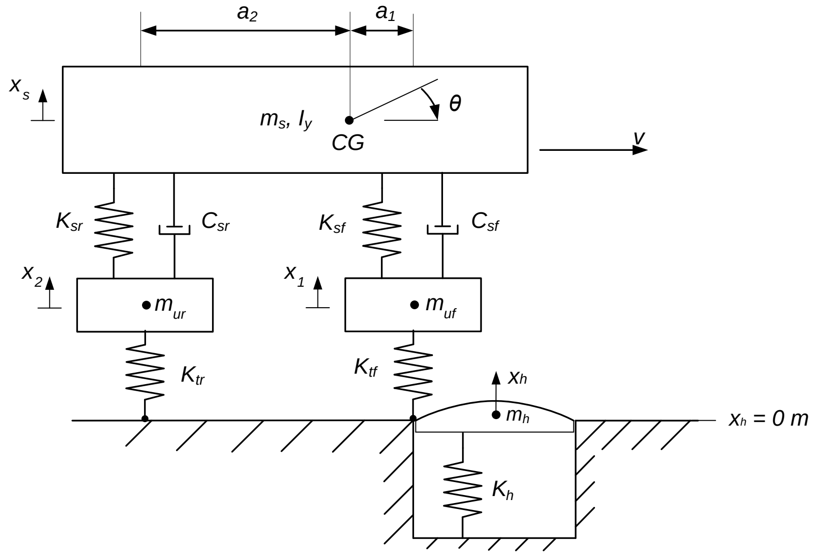


Fig. 4. *Bicycle car model with a movable surface applied on the pavement.*

$$m_s\ddot{x}_s + C_{sf}(\dot{x}_s - \dot{x}_1 - a_1\dot{\theta}) + C_{sr}(\dot{x}_s - \dot{x}_2 + a_2\dot{\theta}) + K_{sf}(x_s - x_1 - a_1\theta) + K_{sr}(x_s - x_2 + a_2\theta) = 0 \quad (2)$$

$$I_y\ddot{\theta} - a_1C_{sf}(\dot{x}_s - \dot{x}_1 - a_1\dot{\theta}) + a_2C_{sr}(\dot{x}_s - \dot{x}_2 + a_2\dot{\theta}) + a_1K_{sf}(x_s - x_1 - a_1\theta) + a_2K_{sr}(x_s - x_2 + a_2\theta) = 0 \quad (3)$$

$$m_{uf}\ddot{x}_1 - C_{sf}(\dot{x}_s - \dot{x}_1 - a_1\dot{\theta}) + K_{tf}(x_1 - x_h) - K_{sf}(x_s - x_1 - a_1\theta) = 0 \quad (4)$$

$$m_{ur}\ddot{x}_2 - C_{sr}(\dot{x}_s - \dot{x}_2 + a_2\dot{\theta}) + K_{tr}(x_2 - x_h) - K_{sr}(x_s - x_2 + a_2\theta) = 0 \quad (5)$$

$$m_h\ddot{x}_h - K_{tf}(x_1 - x_h) - K_{tr}(x_2 - x_h) + K_hx_h = 0 \quad (6)$$

The energy released from the vehicle is determined using the vehicle speed reduction, which is associated to the lost of kinetic energy, through equation (1).

4. Technical Analysis

Based on a software tool previously developed by the authors to simulate the VRI from an energetic perspective, named RoadVISS (Duarte et al., 2016), the equations of the SRE with a movable surface were incorporated, both for the new surface profiles and for the vehicle dynamics model with a moving surface and a spring.
The purpose of the simulation software is to study this interaction in great detail, with the possibility of fully characterizing the vehicle under study, by defining its class, weight, axles, wheels, geometry, speed, acceleration, suspensions and tires, defining all the mechanical parameters, such as damping and stiffness for each suspension and tire, as well as fully characterizing the pavement or SRE surface, by defining its material, shape, geometry and, for a surface with displacement, its maximum displacement, mass, and stiffness. The selected vehicle model for this analysis is the bicycle car model.
The software tool calculates all the displacements, both for the vehicle and the SRE surface, the applied and received forces, and the energy transferred, released from vehicle and received on the SRE surface, presenting the results both graphically and numerically. From the vehicle's chassis displacements and from the motion equations, the software also

quantifies the vertical and horizontal accelerations, important to determine the discomfort induced on the vehicle passengers.

In this section the simulations performed with RoadVISS for two scenarios will be presented: standard speed reducers, without surface motion, and the new SRE proposed, for different surface profiles, maximum displacements and geometries, in order to identify the most effective solution, both in terms of speed reduction and ride quality.

According to Uys *et al.* (2007) and considering ISO 2631-1 (ISO, 1997), the vertical acceleration induced by the vehicle on the passenger is a key factor for measuring the ride quality. According to these references, for a vertical acceleration lower than 0.32 m/s^2, the driving is comfortable; between 0.32 and 0.63 m/s^2, the driving is a little uncomfortable; between 0.5 and 1.00 m/s^2, the driving is a fairly uncomfortable; between 0.80 and 1.60 m/s^2 the driving is uncomfortable; between 1.25 and 2.50 m/s^2 driving is very uncomfortable; and above 2.00 m/s^2 driving is extremely uncomfortable. Thus, it is intended that the SRE do not induce vertical accelerations above 0.80 m/s^2 in the vehicle's chassis.

To perform the simulations with RoadVISS, a four wheeled light vehicle with a 1,500 kg total weight was considered as input, having a 90%-10% relation between sprung and unspung masses and moving at 50 km/h in a free rolling scenario.

4.1. Standard SRE

Considering the SRE available on the market, more specifically commercial speed bumps, which have a convex and sinusoidal profile, with different widths (400, 600 and 900 mm) and maximum heights (20, 30 and 50 mm), and also some products with triangular and trapezoidal surface profiles, as presented in Figure 1, a set of simulations were performed for a vehicle with the presented characteristics, in order to determine the impact of the different SRE on the vehicle, both in terms of maximum induced force form vehicle to the SRE (F_z), vehicle released energy (K), chassis maximum vertical displacement (x_s), maximum vertical acceleration ($\ddot{x}_s$), maximum horizontal acceleration ($\dot{\boldsymbol{v}}_{\boldsymbol{x}}$), and the vehicle speed reduction. The simulation results are presented in Table 1.

Table 1
Standard SRE simulation results

Surface profile	Width [mm]	Max. height [mm]	$F_{z\ max}$ [mm]	Vehicle rel. ener. K [J]	$x_{s\ max}$ [mm]	$\ddot{x}_{s\ max}$ [m/s^2]	$\dot{v}_{x\ max}$ [m/s^2]	Speed reduction [km/h]
Bump S1	400	20	5,691.16	760.00	1.61	2.25	-3.24	0.13
	600	30	6,685.55	1,200.00	3.37	3.58	-3.47	0.21
	900	50	7,739.05	2,248.00	6.48	5.11	-3.82	0.39
Bump S2	400	20	6,588.26	776.00	0.95	1.68	-2.12	0.13
	600	30	7,669.48	1,028.00	2.34	2.95	-2.95	0.21
	900	50	9,738.73	2,680.00	3.89	4.83	-4.1	0.47
Trapezoidal S3	500	30	7,045.11	3,368.00	3.25	3.13	-6.15	0.59
	750	40	8,345.22	4,562.00	5.89	4.04	-6.99	0.79
	1,000	50	10,301.18	5,782.00	8.67	4.94	-7.11	1.01
Triangular S4	400	20	6,006.95	570.00	0.98	1.54	-0.75	0.10
	600	30	7,025.51	864.00	1.79	2.47	-0.83	0.15
	800	40	7,603.11	1,040.00	2.89	3.23	-0.84	0.18

From the results presented in Table 1 it is possible to compare the differences between each SRE, depending on its particular characteristics. Some conclusions can be drawn from the analysis of the results:

- All the analyzed SRE induces a vertical acceleration higher than 0.80 m/s^2, which indicates, according with ISO 2631-1 (ISO 1997), that all SRE induces an uncomfortable ride quality to the vehicle passengers, when passing over the SRE at 50 km/h; in fact, most part of the studied SRE presents a vertical acceleration higher than 2.50 m/s^2, meaning that it induces an extremely uncomfortable ride quality to the vehicle passengers,
- Comparing among each studied SRE, one can conclude that the *Triangular* surface profile (S4) presents the lowest vertical acceleration induced to the vehicle passengers, but is also the profile with the lowest energy extraction and, consequently, the lowest vehicle speed reduction,
- The convex *Bump* surface profile (S1), which is the mostly used profile on municipal roads, specially the version with 600 mm width and 30 mm maximum height, induces an extremely uncomfortable ride quality to the vehicle passengers, and only promotes a direct speed reduction of 0.21 km/h,
- The sinusoidal *Bump* surface profile (S2), when compared with the convex *Bump* surface profile (S1), induces a lower vertical acceleration to the vehicle chassis, so, a lower discomfort to the vehicle passengers, for similar results in terms of speed reduction, meaning that this profile is more appropriated to improve ride quality,
- The *Trapezoidal* surface profile (S3) presents the highest speed reduction values; however, due to the very high vertical acceleration induced to the vehicle passengers, its use should be very limited.

4.2. New SRE with movable surface

Considering the new solution proposed for a SRE with a movable surface and considering the same vehicle and motion conditions as the previous simulations for standard SRE, a set of simulations were performed for the different surface profiles presented in Figure 3, with different widths (200, 400 and 600 mm) and maximum heights (20, 25 and 30 mm), being the maximum displacement equivalent to the surface maximum height. The total spring stiffness is 200,000 N/m, and the surface material is recycled plastic with a rubber layer on top, having a total mass of 20 kg. The simulation results are presented in Table 2.

Table 2
New SRE with movable surface simulation results.

Surface profile	Width [mm]	Max. height [mm]	$F_{z\ max}$ [mm]	Vehicle rel. ener. K [J]	$x_{s\ max}$ [mm]	$\ddot{x}_{s\ max}$ [m/s^2]	$\dot{v}_{x\ max}$ [m/s^2]	Speed reduction [km/h]
Ramp S5	200	20	3,634.22	574.00	0.12	0.36	-0.61	0.10
	400	25	3,471.54	490.00	0.07	0.38	-0.35	0.09
	600	30	4,507.51	534.00	0.16	0.99	-0.42	0.10
S profile S6	200	20	3,848.77	242.00	0.17	0.37	-1.13	0.04
	400	25	3,934.52	224.00	0.15	0.34	-0.83	0.04
	600	30	4,888.78	326.00	0.14	0.92	-0.65	0.06
ScaleUp S7	200	20	3,077.12	90.00	0.08	0.46	-0.44	0.02
	400	25	2,937.22	130.00	0.28	0.52	-0.65	0.03
	600	30	3,619.58	224.00	0.40	0.62	-0.10	0.04
Crest S8	200	20	4,203.21	844.00	0.63	1.05	-3.35	0.15
	400	25	4,157.48	912.00	0.73	0.96	-3.18	0.16
	600	30	4,290.05	938.00	1.18	0.86	-3.19	0.16

From the results presented in Table 2, it is possible to compare the differences between each surface profile and SRE characteristics. Some conclusions can be drawn from the analysis of the results:

- Surface profiles *Ramp* (S5), *S profile* (S6) and *Scale Up* (S7) induces a vertical acceleration lower than 0.80 m/s^2, for a 200 and 400 mm width, meaning that these three surface profiles allows a passage with a comfortable or little uncomfortable ride quality, while energy is being harvested from the vehicle, leading to a speed reduction,
- Surface profile *Crest* (S8) induces a vertical acceleration between 0.86 and 1.05 m/s^2, values that are considered uncomfortable in terms of ride quality,
- In terms of speed reduction, *Crest* is the surface profile that allows to harvest more energy from the vehicle and, consequently, to maximize its speed reduction, followed by the surface profile *Ramp*, *S Profile* and *Scale Up*, respectively,
- The surface profile that presents the best relation speed reduction versus ride quality is the *Ramp* (S5), with special emphasis for the 200 mm width and 20 mm maximum displacement equipment, that allows to reduce the vehicle speed in 0.10 km/h only in 0.20 meters, meaning that with five consecutive devices applied in the pavement it would be possible to have a 0.50 km/h speed reduction in only one meter, with a good ride quality (little uncomfortable).

5. Conclusion

In this work a new solution was proposed to reduce vehicle speeds by extracting kinetic energy from their motion, being applied directly in the road pavement, making it impossible for the vehicles to overcome it without interact with it. This solution is different from the existing SRE, as it has a one degree of freedom movable surface, with a specific profile and geometry that allows to minimize the impact on the vehicle, keeping acceptable ride quality and without affecting vehicle passengers.

The existing SRE have a small impact in vehicle speed reduction, lower than 0.50 km/h for the most used speed bumps (S1 and S2), inducing however a great discomfort to the vehicle passengers, with vertical accelerations higher than 2.0 m/s^2 for almost all equipment. From all the simulations, it can be concluded that all SRE induces very uncomfortable or extremely uncomfortable ride quality to the vehicle passengers, while do not induces high values of speed reduction to vehicles. The effectiveness of these devices is due to the discomfort caused to vehicle passengers, which leads to a speed reduction before the equipment due to a braking action, and not by the equipment captured energy.

When comparing the results achieved with a movable surface and surface profiles S5-S8 to the standard SRE with surface profiles S1-S4, one can conclude that the relationship vehicle speed reduction versus ride quality is much better for the new proposed device with movable surface, for all the studied surfaces, both in terms of speed reduction and ride quality.

Different surface profiles and dimensions were evaluated, and the solution that presents the best relation between the energy harvested from the vehicle and the vertical acceleration induced to the vehicle chassis is the *Ramp* surface profile, with 200 mm width and 20 mm maximum height, having a maximum displacement of 20 mm. When comparing with standard speed bumps, it can extract 44% more energy for the same width, with an impact on the vehicle chassis 90% lower, for the same device height.
The main difference of the proposed solution when compared with the existing equipment is that speed reduction is performed by extracting energy from the vehicle without any action of its driver, instead of inducing a great discomfort on the vehicle occupants.
Has the movable surface concept induces both a small vertical acceleration and a chassis vertical displacement (lower than 1 mm for almost all scenarios), it allows to implement multiple SRE consecutively on the pavement, without or with a very small distance between each other, allowing to maximize the vehicle speed reduction in a very small distance.
The next steps of the current research will be the design of a SRE with the proposed characteristics and the experimental development with a prototype construction and laboratorial tests, before the real environment tests be performed.

Acknowledgements

The present research work has been carried out in the framework of project PAVENERGY – Pavement Energy Harvest Solutions (PTDC/ECM-TRA/3423/2014), co-financed by the European Regional Development Fund (ERDF) through the Operational Programme for Competitiveness Factors (COMPETE) and by national funds through the Portuguese Foundation for Science and Technology (FCT). The author Francisco Duarte is also grateful to the Portuguese Foundation of Science and Technology for the financial support provided to this study through Grant SFRH/BD/95018/2013.

References

Blundell, M.; Harty, D. 2004. *Multibody systems approach to vehicle dynamics*, Elsevier Butterworth-Heinemann, Oxford, UK.
DGV 2004. *Technical Paper - Installation and signalization of speed reducer bumps (In Portuguese)*
Duarte, F.; Ferreira, A.; Fael, P. 2016. Software for simulation of vehicle-road interaction. In: *New Advances in Information Systems and Technologies*, of the *Series Advances in Intelligent Systems and Computing*. Switzerland: Springer International Publishing, 444: 681-690.
Elvik, R.; Vaa, T.; Erke, A.; Sorensen, M. 2009. *The handbook of road safety measures*. Emerald, Bingley, UK.
Ewing, R.; Brown, S. 2009. *U.S. traffic calming manual*. Chicago, Ill.: American Planning Association, Chicago, U.S.A.
Freitas, E.; Machado, P.; Santos, J.; Pereira, P. 2013. Planos de ação de redução do ruído: consideração do custo benefício de superfícies de baixo ruído e do impacto de medidas de gestão da velocidade (*In Portuguese*). In *Proceedings of the XVII Congreso Ibero-Latinoamericano del Asfalto-CILA*.
Gifford, R. 2004. *Road Humps should be dug up: The Case Against*, Parliamentary Advisory Council for Transport Safety, London, UK.
Gillespie, T. 1992. *Fundamentals of vehicle dynamics*, Society of Automotive Engineers Warrendale, U.S.A.
Hongqiao Traffic 2016. Speed hump. Available from Internet: <http://www.hongqiao.cc/english/index.asp>.
ISO 1997. Mechanical vibration and shock - Evaluation of human response to whole-body vibration. Part I: General requirements. *ISO 2631-1*, Geneva, Switzerland.
Jazar, R. 2008. *Vehicle dynamics: theory and application*, Springer, New York, U.S.A.
Johnson, L.; Nedzesky, A. 2004. A comparative study of speed humps, speed slots and speed cushions. In *Proceedings of the ITE Annual Meeting Compendium, Institute of Transportation Engineers (ITE), Washington, DC*.
Popp, K.; Schiehlen, W.; Kröger, M.; Panning, L. 2010. *Ground vehicle dynamics*, Springer, Berlin, Germany.
Rajamani, R. 2011. *Vehicle dynamics and control*, Spinger, New York, U.S.A.
Seco, A.; Gonçalves, J.; Costa, A. 2008. Manual do planeamento de acessibilidades e transportes (*In Portuguese*). Porto: CCDRN.
Silva, J. 2010. *Modelação e Avaliação do Potencial de Desempenho das Lombas Redutoras de Velocidade (In Portuguese)*. Doctoral Dissertation. University of Coimbra. Coimbra, Portugal.
Szurgott, P.; Kwasniewski, L.; Wekezer, J. 2009. Dynamic Interaction Between Heavy Vehicles And Speed Bumps, *ECMS*, 585-591.
TSS 2016. Traffic Safety Store. Available from Internet: <https://www.trafficsafetystore.com/>.
Uys, P.; Els, P.; Thoresson, M. 2007. Suspension settings for optimal ride comfort of off-road vehicles travelling on roads with different roughness and speeds, *Journal of Terramechanics*, 44(2): 163-175.
Wong, J. 2001. *Theory of ground vehicles. 3rd Edition*, Wiley, New York, U.S.A.
WHO 2010. *European Status Report on Road Safety: Towards safer roads and healthier transport choices*, World Health Organization.
WHO 2013. *Global status report on road safety 2013: supporting a decade of action*, World Health Organization.

3M 2016. Speed Bumps. Available from Internet: <http://www.3m.com/3M/en_US/company-us/>.

METHODOLOGY OF ENVIRONMENTAL DAMAGE ASSESSMENT CAUSED BY ROAD ACCIDENTS

Vladimir Adamec[1], Barbora Schullerova[2], Pavel Bulejko[3], Mario De Luca[4], Francesca Russo[5]
[1,2] *Brno University of Technology, Institute of Forensic Engineering, Czech Republic*
[3] *Brno University of Technology, Faculty of Mechanical Engineering, Czech Republic*
[4,5] *University of Naples "Federico II", Department of Civil Construction and Environmental Engineering, Italy*

Abstract: The current status of assessing the amount of environmental damage is mainly focused on the long-term consequences of negative factors, such as traffic and industry emissions. Significant damage may be caused even due to short-term effects, such as an accident during transportation of hazardous substances, where there is a loss caused either by the vehicle failure, or road accident. Damage which is subsequently solved, in most cases reflects only the costs associated with the removal and rehabilitation of the affected area. It is however important to note that since the damage occurrence until the return of the environment to its original state, if at all possible, there are many changes bearing other related costs associated with their replacement. The paper analyses the current status of assessing the amount of environmental damage and suggests appropriate methods for the unification process in the framework of expert activities.

Keywords: traffic, road accident, environment, damage, assessment, valuation.

1. Introduction

The assessment of environmental damage amount is associated with high demands on knowledge in science, technology and economics. Damage to the environment can occur for a variety of reasons, but mostly due to anthropogenic activities. Human society is an important factor which affects the nature and its resources, both in positive and negative ways. Damage can be caused due to prolonged exposure of negative factors such as industry or traffic. In the short-term effect it is an accident at stationary objects with the loss of dangerous chemicals. These events are a part of the issue of environmental protection, which is becoming one of the priorities of the European Union (EU) and other developed countries. However, the accidents with the dangerous chemicals during their transit are not taken into consideration adequately primarily in terms of legislation. One of the reasons could be in this case the mobility and the lack of ability to predict where the event could occur, under what conditions and what character of the affected site there would be. The complexity of the situation is also enhanced by the fact that there is currently no unified process to assess the amount of potential damage to the environment. The current methodology of solutions is based primarily on experts' experience and on the expert knowledge of application of methods not only in the Czech Republic but also abroad. The chosen methods are most often based on cost method of valuation, especially for removal and rehabilitation work related to accidents. It is however important to realize other connections, such as damage to the environment components and an inability to fulfil their functions. Because of the ever-increasing frequency, the volume of the transported dangerous chemicals and the absence of determination of transport routes, the risk of serious damage to the environment after the accident increases. Therefore, it is important to look for possible approaches for the unification of the assessment of the amount of already incurred or arising damage in a comprehensive manner, which does not reflect only the costs of certain measures.

2. Analysis of the current state

Currently, the quantitative expression value of the assessed entities is preferred while the valuation of the environment. The applied methods focus primarily on production (market) feature of natural components which are in most cases private goods. For the non-productive (non-market) functions of these components the methods based on a qualitative and often a heuristic approach are frequently chosen. This discrepancy is getting into a confrontation with the use of these components of the environment in which a person uses both functions simultaneously, as nature creates a complex system with the mutual interaction of the link between its elements. From this perspective, it is necessary to choose a comprehensive solution and to realize mutual connections in cases such as the damage to the environment after the loss of dangerous chemicals during their transportation caused by the disruption of links and elements of the environment. The first part analyses the problem of valuing the environment in order to define approaches for assessing the value of individual natural ingredients and their components. Subsequently the methods of assessing the amount of damage were analysed which can be applied in the event of accidental release of hazardous substances into the environment.
The assessment of the value of natural resources is exercised mainly in products which are traded on the market, as stated, for example, by Mendelsohn and Omstead (2009), Frey et al. (2009) or Sawe and Knuston (2015). From the perspective of an expert the activity valuation is then necessary, for example, to assess what impact the negative factors have on the environment or its components, or what is the yield value of natural production ingredients. However, the question still is, why the environment is not generally classified as a system, with all its benefits, and not only market ones.

[2] Corresponding author: barbora.schullerova@usi.vutbr.cz

The preference of valuation of production components of the environment is also evident from the perspective of EU (European Commission, 2016) and Czech legislation (Act No. 151/1997 Coll., on Property Valuation). Therefore, it is currently possible to seek solutions in the set of partial findings arising from the experience with the application of the methods of valuing the environment not only in the Czech Republic but also abroad. The inconsistency in the approach of the environment value underlines the need for a solution in search of a unified approach of assessing the amount of damage to the environment.

Damage to the environment is defined by Act No. 17/1992 Coll. on the Environment when it leads to the occurrence of a greater concentration of chemicals in soils, water and other natural ingredients and may even reach the level of environmental burden. Another interpretation of the terms in the legislation relates mainly to long-term sources of environmental pollution or accidental loss of dangerous chemicals from stationary objects which deal with these substances. An example is Directive 35/2004 / EC, which was implemented in the Czech legislation, specifically Act No. 167/2008 Coll. on Prevention of Environmental Damage. In case of damage of the environment the rule is laid down - the polluter pays, along with the ways of remedying it. At the same time, however, certain activities are excluded from the scope, which include the transportation of dangerous substances. The method of damage compensation is further defined in the Act No. 89/2014 Coll. of Civil Code, but only in respect of pecuniary damage, where a specific environmental component must be a subject of property.

2.1. Methods of the assessment of the amount of damage to the environment

The choice of methods of assessing the amount of damage caused to the environment component is based on the nature of the damage and the events that caused it. To select a particular method, the initial information gathering and its analysis are necessary. Additionally, the experience or expert studies of events that have already happened can be taken into consideration and the amount of damage has been assessed. Some of the current methods arose from research projects; others were made for specific cases and the nature of the damage, such as oil spillage and contamination of water sources. It is also important to emphasize that even though some methods and approaches are designed for stationary sources of pollution, some of these methods can be applied to solve the assessment of the amount of damage to the environment in connection with the transport of hazardous substances, or to use their methodology to combine them with other methods (Adamec et al., 2016a). The methods based on the cost method are most often chosen (Quantification of damage to the environment based on the renewal / replacement cost, Quantification of environmental damage based on changes in productivity, the Method of cost of prevention, damages or renewal of environmental resources, the Method of opportunity cost of the so-called opportunity costs, etc.). The above-mentioned methods are based on the principle of preferential and non-preferential access, as is in the case with the methods of valuing the environment (Tošovská, 1999, McCracken- Rietbergen and Abaza, 2000, Roosberg and Thorsteinsson, 2002, Seják, 2010). The loss of value of the damaged components of the environment, and the given costs of preventing damage or vice versa removal of damage are monitored. Although this approach may seem to be sufficient, it is necessary to point out that every methodology of each method is different and does not cover the total spectrum of damaging of both the production and the non-production functions and components of the environment.

2.2. Risks of assessing the amount of damage to the environment

The selection of the correct method with regard to the abovementioned becomes a risk activity when the application of only one method or its improper use may cause obtaining poor or insufficiently meaningful results. The risks associated with the assessment of the amount of damage to the environment include, for example, a poor definition of the evaluated area, conceptual inconsistencies, identifying only visible damage to the environment, a wrong choice of valuation methods, insufficient information and analysis of the evaluated area, ignorance of the applied methods, the individual evaluation without using an objective view of the surroundings, a lack of feedback control and etc.

Those risks are only a partial list of possible factors which may have an adverse effect on the final outcome of the process of assessing the amount of damage. Therefore, the application of methods of engineering risks was selected. Specifically, the analysis "What will happen if ..." was chosen, Fault Tree Analysis (FTA) and Event Tree Analysis (ETA), whose task was to identify and verify whether all detected damage to the environment caused in connection with accidents and loss of dangerous chemicals as well as if characterized damage is related to this event and could not be caused by any other factor of the surroundings (Roosberg 2002, Nilsson 2003, Burgmann, 2005 Adamec et al., 2011 Aven, 2014 Adamec et al. 2016b). The method of analysis Check List was further applied to the draft, whose purpose is to keep the individual procedure steps and their accuracy. The importance of addressing issues of transportation and loss of dangerous chemicals into the environment, where they cause damage, emphasized the result of the analysis of the current state of the transport of these substances on the road.

2.3. Risks of transportation of dangerous chemicals in connection with the occurrence of damage to the environment

In the Czech Republic road, rail and ship (river) transport are most frequently used to transport dangerous chemicals. The most frequent type is road transport according to the international agreements ADR (ADR, 2015), among which the major threat is the ever-increasing volumes and unspecified, or better said unset routes through which the transportation is done (Schüllerová, 2014). The most commonly transported dangerous chemicals are flammable and highly flammable substances such as gasoline, diesel and heating oil, referred to the 1202 and 1203 UN code (Bocana, 2014), within EU countries about 4-8% of the total goods transportation. More than 50% of transported volumes are flammable liquids, mostly in the form of fuel, followed then by compressed and liquefied gases. In 2013 in some European countries an increase in transported volumes of almost 100% was recorded (Estonia, Luxembourg, and Great Britain). In the Czech Republic the international transportation prevails, which reaches almost 60% of representation, and from 2010 to 2014 the quantities of transported quantities had risen [mil.tkm] by 22, 3% (Eurostat, 2016). The statistical data provided by the Police Presidium of the Czech Republic shows that every year nearly one hundred of road accidents involving vehicles under ADR occur (Bukovsky, 2015). The result of the loss of dangerous chemicals escaping can have a different character in connection with the adverse effects on the environment (Garbolino et al., 2012):

- the explosion of expanding vapour of boiling liquid, the so-called BLEVE – the damage is caused by a hot explosion stream,
- the explosion of cloud formed by flammable gases and vapours, the so-called UVCE – the damage is caused by the effects of overpressure,
- the loss of toxic substances and mixtures of undesirable impact on humans and the environment.

Dangerous chemicals can be spread into the atmosphere, if the substances are in gaseous form, liquids can distribute by infiltration, flushing or discharge. The spreading of the substance loss can be also influenced by a slope of the terrain, porosity, composition and the type of affected soil, the absorption capacity, the type of soil micro flora, soil moisture, current weather conditions, time of exposure, but also the time between the accident occurred and the start of rehabilitation. Particularly dangerous are such substances against which the environmental components are vulnerable and these substances are toxic for them.

3. Materials and Methods

To solve the problem of the absence of a unified methodology for assessing the amount of damage to the environment, a systemic approach and its attributes according to Janíček (2014) were selected. For their definition and the settings methods of engineering risks were chosen as supporting tools. Simultaneously the approaches for assessing the vulnerability of affected components of the environment and the categorization of damage incurred were created in connection with dangerous chemicals loss into the environment and their consequences.

3.1. Attributes of a systemic approach to assess the amount of damage to the environment

Based on the researched methods and approaches to assess the amount of environmental damage caused in connection with the transportation of dangerous chemicals especially on the road, it was assessed that it is necessary first of all to choose a general approach on the basis of which different methods and procedures will be chosen. The system approach fulfils these requirements and is thus a suitable choice to solve the stated objective, because it is formed gradually and by logically related steps. The basic attributes of the systems approach are:

- The definition of the area of interest,
- The approaches to problem solving,
- The assessed specifications of the area of interest,
- The definition of methods for analysing the considered area,
- The ethical standards and compliance with them.

3.2. The use of risk engineering methods to assess the amount of damage to the environment

The system approach is also implemented in methods of engineering risks, some of which have been chosen as a support tool to assess the amount of damage to the environment. Their importance is reflected primarily in identifying, analysing and evaluating of the extent of the consequences arising from the accidental loss of dangerous chemicals. They are also a tool for controlling the operations conducted and their correctness, thereby minimizing the risk of inadequate interpretation of results and the subsequent assessment of the amount of damage which is not complete. The risk assessment is based on available information collection, data analysis to determine solutions and formulate problems, application of risk analysis for the identification and characterization of potential incurred damages, risk and identified damage assessment divided according to the importance.

The applied methods are based on a qualitative approach and are used for identification and definition of the assessment area and identification of interdependencies in terms of the impact of the accident on the environment. When applying this approach, a more precise definition of the first group of system attributes is achieved. The chosen methods of engineering risks, which are based on this approach, include:

- The Check List Analysis (CLA) is a simple method, which is based on creating a list of steps, tasks or items, according to which the completeness or accuracy of the method is verified.
- The analysis "What will happen if ..." (What If Analysis) helps to create a basic framework for defining locations where damage can be assumed and characterized,

- Fault Tree Analysis Method (FTA) based on a deductive approach helps to find the root causes of the peak events such as damage to the environment at the crash site.
- Event Tree Analysis Method (ETA) is a method based on an inductive approach to identify possible consequences of the events and the probability of their initiation Aven (2014). In this case, it is an accident during transportation of dangerous chemicals and the consequences of the damage caused. The application of ETA method will help to create a presumption of the extent of the accident and to identify the potential damage that may not be obvious at first sight.

Identification of damage according to vulnerability due to dangerous chemicals loss

Vulnerability is an important property of components and elements of the environment, which is important to be implemented into the process for assessing the extent of the damage. The advantage of this feature is that based on the assessment of the elements of the affected area, any damage incurred and its importance can be more easily identified. The valuation is based on the definition of ecotoxicity of the dangerous chemicals loss and their amounts, including determining the extent of contamination of production and non-production functions of components of the environment.

Modelling of emergency situations

The results will be verified on a model situation of the accident with the dangerous chemicals loss to the chosen destination. This phase of a solution requires at the same time the assessing of demands to assess the extent and amount of damage, which is different in each case of the damage. The software tool Areal Locations of Hazardous Atmospheres (ALOHA 5.4) will be used, which was created by U. S. EPA and NOAA (U. S. EPA, 2016). This software is freely available and can be used free of charge. The software is used for modelling the dangerous chemicals loss with a possibility to display outputs in the map data, such as geographic information systems (GIS) or Google Earth map data (Google, 2016).

3.3. Methods for assessing the amount of damage to the environment

The methodology for assessing the amount of damage to the environment will be based on ensuring comprehensiveness in accordance with predefined attributes of a systemic approach. Choosing of the recommended methods is based on a prior evaluation of the extent of the damage and its importance according to the risk categorization made according to form, meaning and affected environmental components. The recommended methods for assessing the amount of damages will create a suitable combination to assess the damage to public and private environment estates, including the measures to ensure the safe transportation and measures applied to their removal and rehabilitation of accident and damage incurred.

4. Results

The implementation of a system approach to the issue of assessing of the amount of damage to the environment, in connection with the transportation and the loss of dangerous chemicals during the accident, contributed significantly to the achievement of the results presented here. At the same the methods of engineering risks were used as support tools for identification, analysis, evaluation and characteristics of the damage incurred and also as a control tool for minimizing the risk of errors. Given the complexity of solving this problem the assessment of vulnerability of components of the environment and the classification of damage caused to the environment have been also included into the overall process. The procedure of setting requirements for respecting the systems approach, together with methods of determining the extent and importance of damage, has been used to create a user-friendly software tool, which aim is to determine the importance of damage to individual components of the affected area and to define the recommended methods for assessing the amount of damages.

4.1. Application of a system approach to assess the amount of damage to the environment during an accident while transportation of dangerous chemicals

The system approach and its application to solving specific problems, was chosen considering its complexity and unity, which is very significant for a solution to assess the amount of damage to the environment. The basic methodology has been used in order to meet the necessary steps for its implementation (Figure 1). At the same time the support tools and methods were implemented, whose task was to provide a comprehensive, qualitative and easy way to assess the amount of damage caused to affected components of the environment where there was a contamination or otherwise unwanted results of the dangerous chemicals loss.

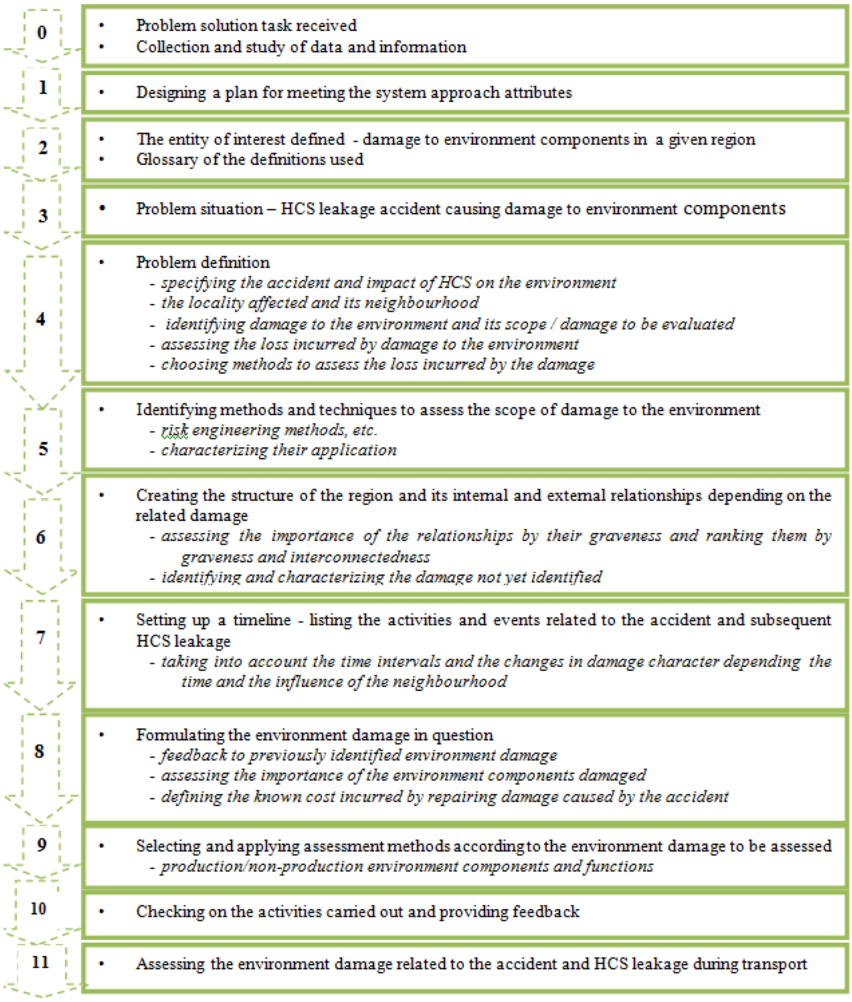


Fig. 1.
System approach activities (algorithm)

4.2. Application of risk analysis to identify and assess the damage to the environment in connection with accidents and the loss of dangerous chemicals during transportation

To correctly implement the mentioned attributes, the methods of risk engineering were chosen, which allow based on the controlled methodology to identify and describe the extent of damage (Figure 2). Also the purpose of their application is to minimize the risk of errors and to increase the quality of outputs. Mainly qualitative methods were used within the various stages of preparation and application of the design of the proposed approach - identification and definition of the particular entity and its solutions, identification and characterization of damage incurred or potential damage to the environment based on the analysis during the accident, checking of the correct and complete application of the systems approach for assessing the amount of damage to the environment (Table 2).

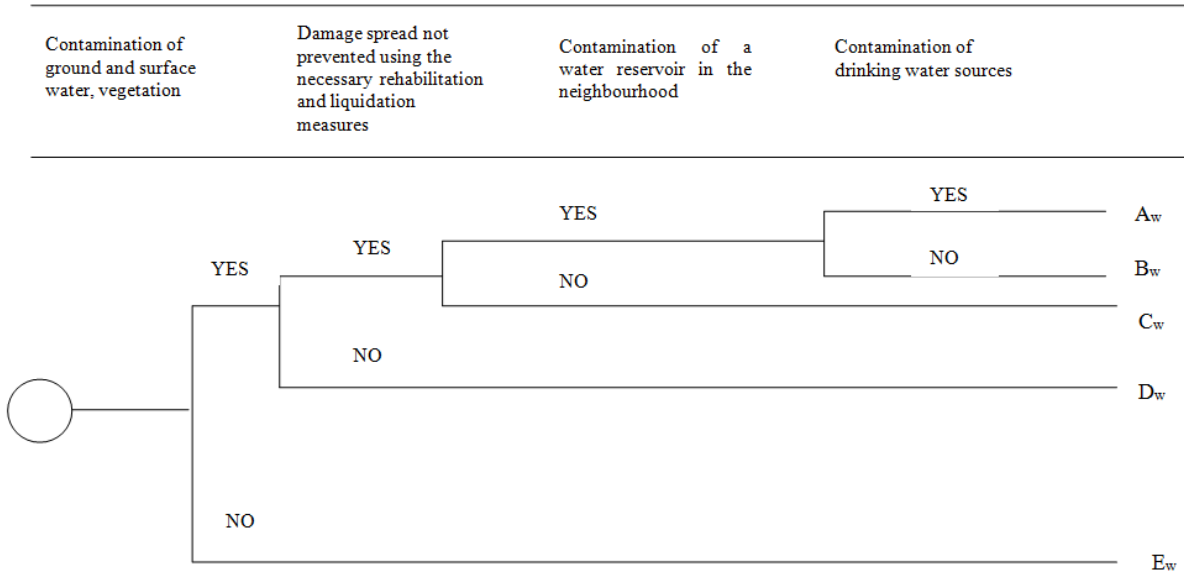


Fig. 2.
Examples of ETA analysis application and damage identification for a particular environment component (water environment – w)

Table 1
Example of assessing the ETA analysis final events for water environment (w)

Final element	**Meaning**
A_w	HCS has spread into neighbourhood through ground and surface water, damage to vegetation, loss of animals are expected, more damage than for B_v assumed). Trout water in part of a river or stream contaminated. A fish farming water reservoir contaminated. Drinking water sources contaminated through ground water.
B_w	HCS has spread into neighbourhood through ground and surface water, damage to vegetation, loss of animals are expected, more damage than for C_v assumed). Trout water in part of a river or stream contaminated. A fish farming water reservoirs contaminated. Contamination of drinking water sources prevented.
C_w	HCS has spread into neighbourhood through ground and surface water, damage to vegetation, loss of animals are expected, more damage than for D_v assumed). Trout water in the affected part of a river or stream contaminated. Contamination of water reservoirs prevented.
D_w	Damage caused in the place of leakage (spread prevented), damage to vegetation, loss of animals expected.
E_w	The spreading HCS has not contaminated ground or surface water.

4.3. Vulnerability assessment of environmental components related to damage occurrence

Damage to the environment is varied as mentioned in the chapters above. Among the significant factors is the vulnerability of the components and elements within the area affected. Based on the application of the methods mentioned, damage has been defined including its brief characteristic, which is related to the area affected. If the vulnerability element is considered in the assessment, the expert will be able to determine the seriousness of the damage better. For this purpose, a simple assessment procedure has been established, which is based on qualitative assessment. The following characteristics have been specified to be used as the basis for a qualitative assessment, the assessment of the degree of vulnerability, the endangered function of the environment, the seriousness of the disruption to the environmental function considering the necessary corrective measures.

4.4. Categorizing environmental damage to determine its degree

Following the vulnerability assessment of the area affected and the identification of the vulnerable places, the characterization of the damage occurring may begin. By characterizing the environmental damage which has occurred, it may be classified and categorized based on its seriousness. Based on this categorization, the expert will be able to obtain an overview of all the damage caused or the damage that may still manifest itself after the accident in connection with the effect of HCS. At the same time, it will be possible to evaluate whether suitable measures have been applied to eliminate and repair the damage.
The categorization of environmental damage related to the transport of HCS was based on processing data on real accidents during the transport of HCS. The statistical data evaluated were provided by the Police of the Czech Republic

(Bocán, 2014, Bukovský, 2015). Based on this analysis, characteristics have been established describing the nature of the accident related to the damage occurrence as well as the nature of the environmental damage occurring afterwards. Specifically, it is the stage in which the accident happened, the type of the HCS, its toxicity and other dangerous properties, the amount of the HCS leaked with regard to the toxicity, the components affected with regard to the ecotoxicity, the components affected with regard to the established vulnerability in relation to the HCS leaked.

4.5. A proposal of a solution methodology procedure

Based on the results obtained, a proposal of a unified approach to determining the amount of damage to the environment related to an accident during the transport of HCS has been outlined. A solution methodology has been developed based on the knowledge about the current situation in determining the amount of environmental damage, about the transport of HCS on roads and the approaches and methods suitable to be implemented in the issues in question. This methodology responds to the fact that there is no unified procedure which would be both clear and which would minimize the risk of omitting some environmental damage. That is why basic rules have been set for applying each particular method and approach.

The basic approach, which permeates the entire methodology, is a system approach. The risk engineering methods selected and the vulnerability assessment and damage categorization have been applied as a support tool for fulfilling the attribute of a system approach, making the solving of complex problems clearer and improving the quality of results.

The rules mentioned have been divided into three stages within which the individual assessment steps are introduced. The preparatory stage focuses on the right specification of a problematic situation and the problems that arise from it. First of all, however, a specific entity of interest must be defined. It is defined based on the attributes of a system approach. They are supplemented by the recommended risk engineering methods; the „What happens if..." method (identifying the components and elements of the area affected and determining the basic assessment boundaries), the ETA method (creating scenarios and identifying the interrelations between the damage and the affecting factors), the FTA method (verifying the causes leading to the occurrence of the environmental damage in connection with an accident during transport and the leakage of HCS). Each step must be accompanied by a recheck, which has been included in the proposed approach in the form of a Check list, which does not allow obtaining a specific result if a certain step is not carried out.

In the second stage, the extent of environmental damage is determined including its characteristic and classification based on the environmental elements affected. Its seriousness is also described with regard to the liquidation and corrective measures already taken and the current state being assessed. Therefore, this characteristic is then analysed using the risk engineering methods and their classification by the environment components affected, the assessment of the seriousness of the damage to the environment regarding the vulnerability, which is described by the rules for assessing and classifying environmental damage using the existing classification method. Based on the assessment of the damage to the environment, methods can be chosen for determining the extent of the damage caused.

The first two stages constitute a clear and comprehensive base which will allow the expert to use the selected methods. The selection of the methods for determining the extent of damage should take into consideration not only the liquidation costs but also other factors such as preventive or corrective measures. The selection of suitable methods should therefore be carried out by a combination based on the categories of liquidation, correction, prevention, and compensation.

The selection of the methods for determining the extent of damage which are in compliance with the categories mentioned should produce a comprehensive set of methods which will help to determine an objective and unified total extent of environmental damage. With regard to the place of the accident occurrence and its extent, it is suitable to also select methods based on preferential evaluation or to include this method in the given combination. This mainly concerns accidents involving the leakage of HCS with a significant impact on the surroundings, when the area is either completely devastated or it cannot be used in the usual way for a certain time interval. One of the examples is a ban on entry into the forest or other areas intended for recreation, social purposes etc. Forming the right combination of methods depends on the basic algorithm created with regard to the preceding stages and specific problems which are solved on a given entity.

4.6. Environmental damage assessment methodology and its application to a software tool

When the proposal mentioned was being prepared, another problem had to be dealt with. It was the uncertainty concerning the uniformity of recording the required information and data and a possible loss of orientation during the application to a specific case. That is why a simple programme has been developed allowing the expert to proceed step by step and form a comprehensive basis for determining the extent of environmental damage. The tool selected for this programme is Microsoft Office Excel 2007 (Microsoft, 2016). The reason was its enhancement and easy usage. The programme setting is based on a simple algorithm of meeting or not meeting a specific condition. As Table 2 shows, there is a total of seven stages, the last of which serves as a checking one. Stages A – G consist of 33 steps including help for filling them in.

Table 2
Division of the stages of the software tool

Marking	Name
A	Familiarization with the task
B	The location of an accident involving leakage of HCS
C	Leakage of HCS
D	Damage to the environment
E	The extent and seriousness of the environmental damage caused
F	Time axis
G	Checking

Checking whether the steps and stages have been fulfilled is accompanied by verbal and graphical coloured illustrations. If all the steps in one of the stages have been fulfilled, it becomes highlighted in green, the help disappears and it is possible to proceed to the next stage. However, if any of the steps is not fulfilled, the check boxes remain red. This may happen in two cases:

- some of the steps have not been fulfilled or the answer is not given in an appropriate form,
- fulfilling the step is not possible since the required condition has not been met.

In the first case, each step must be checked again in the stage where the check boxes remained red and they must be completed. In the other case, the checking stage provides help which says how to proceed. For example, where information needs to be looked up, which step has to be repeated or whether it is possible to determine the extent of damage at all.

Most of the steps were made in the form of a selection from several options offered. Each step is accompanied by help which says whether one of the options should be selected or whether a description is necessary. For stages D-F, the application of the risk engineering methods given is recommended. Stage F is subsequently interconnected with the assessment of vulnerability of the environment. The last stage G was created for secondary checking whether all the stages and steps have been fulfilled and described in the right way. If this stage is fulfilled as well, the results are generated. They are based on specific conditions being met in each stage.

The output is a description of which components of the environment were or may be damaged and an evaluation of the seriousness of the damage. Specifically, damage is specified for water, soil and rock environment and a biotic component. For each of these components, three classification levels of the seriousness and extent of damage have been defined including measures recommended for verifying whether all the damage related to the leakage of HCS during transport has been identified. Each description also contains a recommendation of how the leaking substance can spread in the given environment and where it is therefore necessary to carry out a check using, for example, the results of the monitoring. The basic environmental damage categories have been created as follows:

- highly serious damage,
- serious damage,
- anticipated or less serious damage.

What is also recommended are different methods and their approaches and methods of determining the extent of environmental damage. It is always a combination of methods taking account of the conditions of assessment complexity. The following are selected categories of methods of determining the extent of environmental damage recommended with regard to the defined extent of damage:

- cost-related,
- quantificational,
- preferential.

The number of the recommended approaches and methods depends on the category and the component of the environment affected by the damage (Figure 3). For each one, however, there is a recommended group of methods including the representation of each category.

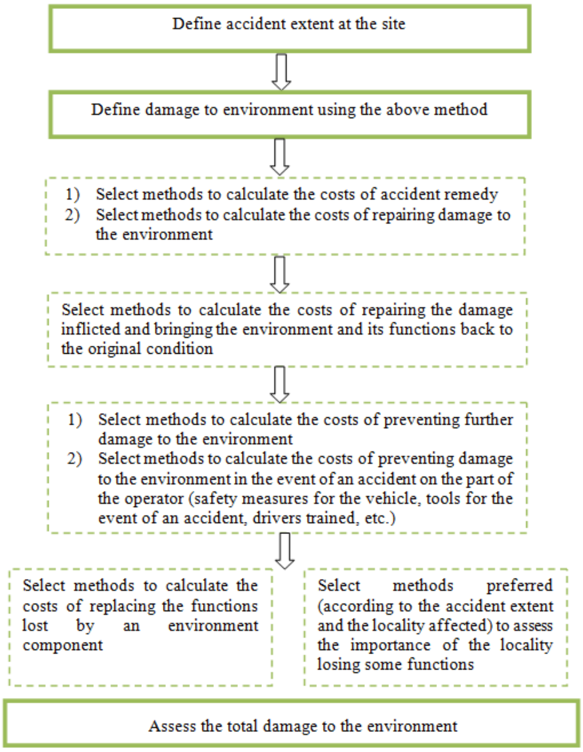


Fig. 3.
Algorithm for selecting methods to assessing comprehensive environment damage cost

It is also important to mention that each accident including the leakage of HCS during transport on roads has its own hazard scenario and development as well as a heterogeneous environment in which it occurs. That is why the methods are recommended not strictly prescribed. Although the software tool was created with an emphasis on its complexity, there are certain limitations which must be taken into consideration:

a) *The veracity of the data entered*

The software tool currently contains a measure checking whether each stage and the steps have been fulfilled. In some steps a warning is also provided if, for example, a verbal statement is given instead of a numerical one. It does not, however, check the relevance and correctness of the values and data entered. This condition cannot be met with regard to the heterogeneity of the events and the variable conditions which occur. At the same time, however, especially the expert must remember the obligation to adhere to ethical standards and the responsibility for the correctness of the information and interpretation of the results.

b) *Entering more types of HCS at once*

If there is leakage of more types of hazardous substances at the same time and their impact on the environment may be different, it is necessary to apply the software tool separately for each type of the HCS. The aim is to obtain relevant data and to ensure that all the damage which occurred or the potential damage has been identified in a comprehensive way including a recommendation concerning the application of the methods of determining the extent of environmental damage.

The aim of creating this software tool was to make fulfilling the requirements for observing a system approach to dealing with a specific field of interest more simple and clear adding support tools.

3. Conclusion

A system approach to determining the extent of environmental damage related to an accident and leakage of HCS during transport is an area where a lot of difficulties must be dealt with. They are for example dealing with these problems within the legislation, the definition of the terms damage to the environment and compensation for damage, differences between accident scenarios which cannot be precisely predicted due to the mobility of the vehicle, the absence of routes designated for transport of HCS with regard to the potential risk etc. The main problem, however, is a missing unified approach which would allow experts to assess the extent of damage and based on which appropriate methods would be selected for determining the total amount. Based on the information obtained, on materials from foreign sources and on consultations with experts, approaches and methods have been selected which are used most often when dealing with these events. It has also been found that these methods most often focus on the expenses connected with liquidation and rehabilitation of the environment, especially in the production functions and components of the environment. That is why the resulting proposal also contains methods taking account of the significance of non-production functions. The solution proposal was subsequently applied in a user-friendly software tool. Further research in this area may continue to be developed attempting to create a universal tool based on a unified and most importantly system approach to assessing environmental damage not only in connection with accidents on roads.

References

Adamec, V.; Schüllerová, B.; Adam, V. 2016. Issues of hazardous materials transport and possibilities of safety measures in the concept of smart cities. In Smart City 360° - LNICS, Social Informatics and Telecommunications Engineering - First EAI International Summit, SmartCity 360, Bratislava, Slovakia and Toronto, Canada, October 13-16, 2015. Revised Selected Papers. Springer International Publishing. 790-799. ISBN: 978-3-319-33680- 0.

Adamec, V.; Schüllerová, B.; Adam, V.; Semela, M. 2016. Issues of hazardous materialstransport and possibilities of safety measures in the concept of smart cities. In EAI Endorsed Transactions on Smart Cities. Extended version. 16(1):e4. Italy: EAI, ICST. Org. DOI: <http://dx.doi.org/10.4108/eai.18-7-2016.151628>.

Adamec, V. et al. 2011. Implementation Action Plan - PS5 - Traffic Safety, *Czech Industrial Platform on Industrial Safety, o. s*., 22 p. (In Czech)

Aven, T. 2014. *Uncertainty in risk assessment – The representation and treatment of uncertainties by probabilistic and non-probabilistic methods*, New Jersey: Wiley. 200 p. ISBN: 978-1-118-48958-1.

Bocán, J. 2014. *Statistical data of road accident, ADR (2009 – 2013*). May 27 2014, 10:50 h; [cit. 2014-08-11]. E-mail communication. (In Czech)

Burgman, M.A. 2005. Risks and decisions for conservation and environmental management. Cambridge; *New York: Cambridge University Press,* xii, 488 p. ISBN 978-0-521-83534-3.

Czech Republic, 2008. The prevention of environmental damage and its remedy. In: *167*. Ministry of Environment Czech Republic. Prague, 53/2008. Available from Internet: <https://www.mkcr.cz/doc/cms_library/02-1682008-1996.pdf>. (In Czech)

Czech Republic, 2012. Civil code. In: *89*. Ministry of Justice Czech Republic, Prague, 33/2012. Available from Internet: <http://www.zakonyprolidi.cz/cs/2012-89>. (In Czech)

European Commission, 2016. Environmental economics – The economics of environmental policy. European Commission, Environment [online]. [cit. 2016-07-07]. Available from Internet: <http://ec.europa.eu/environment/enveco/economics_policy/>. (In Czech)

European Commission, 2013. O*n environmental liability with regard to the prevention and remedying of environmental damage*. European Commission, Luxembourg: Publication Office of the EU. ISBN: 978-92-79-29750-2. (In Czech)

Frey, B.S.; Luechinger, S.; Stutzer, A. 2009. The life satisfaction approach to environmental valuation, *Annual Review of Resource Economics*, 2(4478): 1-31. DOI: 10.1146/annurev.resource.012809.103926.

Garbolino, E. et al. 2012. Transport dangerous goods – Methods and tools for reducing the risks of accidents and terrorist attack, *NATO Science for Peace and Security Series C: Environmental Security*. 249 p. ISBN 978-94-007-2683-3.

Google. Aplikace Google Earth [software]. [Available 2016-02-10]. Available from Internet: <http://www.google.cz/intl/cs/earth/>.

Markandya, A. 2006. The Hedonic Pricing Method. *University of Bath* [online]. [cit. 2015-10-06]. Available from Internet: <ftp://131.252.97.79/Transfer/ES_Pubs/ESVal/hedonics/Hedonicpricing.ppt>.

Marshall, J. 2012. An Intriduction to Fault Tree Analysis (FTA). *Warwick: The Warwick University* [online]. [cit. 2016-06-04]. Available from Internet: <http://www2.warwick.ac.uk/fac/sci/wmg/ftmsc/modules/modulelist/peuss/slides/section_11b_fta_lecture_slides_compatibility_mode.pdf>.

Matos, A.; Cabo, P.; Ribeiro, M.; Fernandes, A. 2010. Economic valuation of environmental goods and services. Forest landscapes and global change. New frontiers in management, conservation and restoration. In *Proceedings of the IUFRO Landscape Ecology Working Group International Conference*. Bragança: IPB, IUFRO. 514-519. ISBN: 978-972-745-110-4.

Mayor, K. et al. 2007. Comparing the Travel Cost Method and Contingent Valuation Method – An Application of Convergent Validity Theory to the Recreational Value of Irish Forests. *Working paper No. 190*, April 2007. Dublin: ESRI. 21 p.

Mendelsohn, R; Olmstead, S. 2009. The Economic Valuation of Environmental Amenities and Disamenities: Methods and Applications, *Annualy Review of Environmental Resources*, 34(1): 325-347. New Haven: Yale University. DOI: 10.1146/annurev-environ-011509-135201.

Microsoft, 2016. Microsoft *Office Excel 2007* [software]. June, 2016. [Available 2016-06-17]. Spreadsheet for Windows requires Windows 2007 and higher level. Available from Internet: <https://products.office.com/cs-cz/home#>.

Nilsson, J. 2003. Introduktion till riskanalysmetoder. *LUTVDG/TVBB--3124--SE*. Fire Safety Engineering and Systems Safety, University of Lund. ISSN 1402-3504.

Robinson, J. 2001. A review of techniques to value environmental resources in coastal zones – *Milestone report. University of Queensland, CEC for Coastal Zone Estuary and Waterway Management* [online]. [cit. 2016-02-01]. Available from Internet: <http://www.ozcoasts.gov.au/pdf/CRC/economic_valuation2.pdf>.

Rietbergen-Mccracken, J.; Abaza, J. 2000. *Environmental valuation: a worldwide compendium of case studies*. Editor Jennifer Rietbergen-McCracken, Hussein Abaza. London: *Earthscan Publications*, vi, 232 p. ISBN: 18-538-3695-8.

Roorsberg, J.; Thorsteinsson, D. 2002. *Environmental and health risk management for road transport of hazardous material*. Lund, Sweden: University of Lund, 2002. 5114 p. ISBN: 1402-3504.

Sawe, N.; Knuston, B. 2015. Neural valuation of environmental resources. *NeuroImage*, 122: 87-95. DOI: 10.1016/j.neuroimage.2015.08.010.

Schüllerová, B.; Adamec, V.; Balog, K. The risk of transport and possibility of their assessment. In Proceedings of *ICTTE Belgrade 2014 - Second International Conference on Traffic and Transport Engineering*. Belgrade, Serbia: 2014. 384-391. ISBN: 978-86-916153-2- 1.

Statistic Austria, 2009. Strassenverkehrsunfälle 2009 . Wien: STATISTIC AUSTRIA [online]. 2010 [cit. 2014-03-15]. Available from Internet: <http://p2.iemar.tuwien.ac.at/p2_10_krems/sites/default/files/strassenverkehrsunfaelle_2009.pdf>.

U.S. EPA. 2016. *ALOHA* [PC program]. Ver. 5.4.4. USA, 2013 [cit. 2016 – 02-10]. Free Available for Windows. Available from Internet: <http://www2.epa.gov/cameo/cameo-downloading-installing-and-running-aloha>.

EVALUATING THE EFFECTIVENESS OF NON-PHYSICAL SPEED MANAGEMENT MEASURES

Stanislaw Gaca[1], Mariusz Kiec[2], Marcin Budzynski[3]
[1,2] *Institute of Road and Railway Engineering, Cracow University of Technology, Poland*
[3] *Gdansk University of Technology, Poland*

Abstract: The subject of the Authors' analyses is a group of non-physical speed management measures. How effective they are depends primarily on how willing drivers are to accept restrictions. Social and cultural factors play a major role. The effectiveness of these measures is not clear and requires further research. The authors conducted such research and evaluated the effects of non-physical speed management measures on driver behaviour and road safety. Changes in behaviour were evaluated by examining speed parameters and how they changed depending on the measure. When evaluating the effects of selected speed management measures on road safety, the analysis looked at crashes using the simple "before" and "after" method with trend control. The so called "power model" was also used for the evaluation with some of its parameters modified.
The research covered: local speed limits, area speed limits TEMPO 20 and TEMPO 30, sections with traffic calming measures and sections with additional speed control signs. Empirical speed tests were conducted at the total of 88 test sites on regional roads. The crash data analysis covered 152 test sites. The research helped to estimate speed reductions caused by the particular speed management measures. Depending on the measure the average speed went down by 6.8-16.3%. The paper includes the results of evaluations studying the effects of selected speed management measures on the crashes. The measures were found to be very effective for serious injury and fatality crashes. Based on speed and crash data coefficients of "power model" were evaluated The effects of the speed management measures under analysis on road safety are strongly linked to local conditions.

Keywords: speed, power model, accident, speed limit, speed management

1. Introduction

Speed management is a set of measures designed to set reasonable speed limits and influence the drivers' choice of speed. This can be achieved through urban planning, infrastructure and traffic layout, enforcement, education and advanced technologies. The basic goal of speed management is to achieve a state of traffic where vehicle speeds are adjusted to the road and traffic making the speeds potentially safe. If properly managed, speed control can help reduce traffic noise and air pollution.
There is evidence from research and practical experience that road safety can be significantly improved through consistent speed management, which includes road engineering measures. There are a number of engineering solutions that can help to reduce vehicle speeds such as road infrastructure design that helps drivers to choose the right speed, physical means to control driving speed and reasonable speed limits. Some of the measures are not very restrictive and leave the decisions to drivers (how willing they are to accept a restriction) and local road and traffic conditions. In this case the actual benefits from changing speeds and better road safety depend on social and cultural factors. As a consequence, overreliance on the results of international speed management research may not offer the same effects in Central and Eastern European countries. This has prompted new research into how different speed management measures affect driver behaviour and road safety. The following measures were studied:

- local speed limits,
- area speed limits TEMPO 20 (residential zone) and TEMPO 30,
- sections with traffic calming measures, sections causing drivers to change vehicle trajectory while maintaining good passage for large vehicles (series of central islands),
- sections with additional sing to inform of a possible speed control.

The paper describes the effectiveness of selected speed management measures and the effect they have on road safety. To that end the power model was used. It was calibrated based on research results. The work is helpful with developing speed management guidelines for Poland's regional and local roads. An overview of speed management measures, especially those less restrictive, precedes the presentation of research results.

2. The effects of speed management on road safety

The effectiveness of speed management measures and how they contribute to better road safety can be analysed using direct (road incident data – collisions and accidents) or surrogate measures that describe the potential hazards. One way to understand the effects of speed management on road safety is to estimate how a specific safety measure has changed. The rate is a quotient of the assumed change in safety on a treated section and the mean value of that same measure on an untreated control section. This is referred to in the Highway Safety Manual as CMF (Crash Modification Factor) which is the basic rate with which to evaluate how different road safety treatments change road safety (CMF; HSM,2010). Table 1 lists selected CMF rates estimated from a variety of international studies for different speed management measures, location (local, regional and national roads), types of accidents and their severity.

[1] Corresponding author: sgaca@pk.edu.pl

Table 1
Estimated CMF rates for different speed reduction measures

Speed management measure	Location	CMF	Type of accident	Accident severity
speed limit reduced by 9 km/h	all	1.17	all	all
speed limit reduced by 16 km/h	all	0.96	all	all
speed limit reduced by 24-32 km/h	all	0.94	all	all
speed bumps	urban, suburban	0.5 - 0.6	all	serious and slight injury
traverse acoustic stripes (horizontal marking)	urban, suburban	0.66	all	all
	urban, suburban	0.64	all	serious and slight injury
comprehensive traffic calming	urban	0.89 – 0.94	all	serious and slight injury
raised pedestrian crossings	urban, suburban	0.54 -0.7	all	serious and slight injury
raised junction	none	1.05	all	serious and slight injury
junction replaced with roundabout on low speed roads	all	1.099	all	all
	all	0.473	all	accidents
edge lines along traffic lanes on straight sections and curves	rural	0.963	speed-related	all
raised cycle crossing	none	1.09	vehicle-cyclist	serious and slight injury
comprehensive traffic calming	built-up – primary network streets	0.92	all	all
TEMPO 30, TEMPO 20 (residential zone)	built-up area	0.40	all	all
	built-up area	0.73		fatality and serious injury
	built-up area	0.68	involving pedestrians	all
	built-up area	0.63	all	fatality
		0.92	all	all

Source: www.cmfclearinghouse.org/resources_hsm.cfm

The effects of a speed management measure on road safety can also be estimated using surrogate rates such as change in vehicle speed as a result of the measure. There is evidence that speed can be used as an surrogate road safety rate known from international and Polish research. The statistical relation between speed and road safety is logical and has been demonstrated many times before (Gaca, 2002, Elvik et al., 2009; Cameron and Elvik, 2010).

To estimate how a change in vehicle speed triggers a change in road safety, we can use the "power model" (Cameron and Elvik, 2010). It helps to predict accidents and accident casualties based on the difference in mean speed "before" and "after" a measure has been applied. To this is used the equation below:

$$W_1 = (V_1/V_0)^a * W_0 \tag{1}$$

where:

W_0 – selected road safety measure in the observation period prior to treatment,
W_1 – selected road safety measure in the same observation period after the treatment,
V_0 – average speed prior to treatment [km/h],
V_1 – average speed after the treatment [km/h],
a –model parameter with the value based on literature or set individually.

A key assumption when using the relation (1) is that during the "before" and "after" analysis, none of the other road safety determinants change, except speed.

Research described in (Cameron and Elvik, 2010) was used to determine the following values of a in equation (1) (Table 2):

Table 2
The a parameter in the "power model" equation

Type of accident	Rural roads		Urban roads	
	***a* parameter**	**Confidence level 95%**	***a* parameter**	**Confidence level 95%**
Fatality accident	4.1	2.9 ÷ 5.3	2.6	0.3 ÷ 4.9
Fatality and serious injury accident	2.6	-2.7 ÷ 7.9	1.5	0.9 ÷ 2.1
Total accidents involving casualties	1.6	0.9 ÷ 2.3	1.2	0.7 ÷ 1.7

Source: Cameron and Elvik, 2010

If we assume the above *a* values, in the case of urban roads a speed limit reduction from 60 km/h to 50 km/h, for the average baseline speed of 60 km/h and a speed reduction of 2.5 km/h, fatality accidents would drop by 10.5% with total accidents going down by 5%. With improved speed limit compliance (e.g. through enforcement or physical means of traffic calming) and a real reduction in average speed by 5 km/h, fatality accidents could drop by 21% and total accidents by 10%.
Table 3 lists the research results of how a reduction in existing speed limits changes the number of accidents and casualties and reduces average vehicle speeds (Austroads, 2010). The measures applied are not very restrictive, i.e. no extra enforcement following the introduction of new speed limits.

Table 3
The effects of new speed limits on average speed and accident reduction

Country	Change of speed limit [km/h]	Recorded change in average speed	Accident reduction
Denmark	from 60km/h to 50km/h (local roads)	3-4km/h	fatalities -24%, serious injury -7%, slight injury -11%
Germany	from 60km/h to 50km/h	-	accidents -20%
Australia (Victoria)	from 60km/h to 50km/h (local roads)	2-3km/h	fatality accidents -21%, serious injury -3%, slight injury -16%, casualty -12%, fatality pedestrian accidents -25%, serious injury pedestrian accidents -40%
Australia (South Australia)	from 60km/h to 50km/h (local roads)	3.8km/h	casualty accidents -20%, serious injury -20%, slight injury from -23% to -26%, fatality -40%
Australia (West Australia)	from 60km/h to 50km/h (local roads)	1km/h	casualty accidents -21%, pedestrian accidents -51%

Source: Austroads Ltd.: Infrastructure/Speed Limit Relationship in Relation to Road Safety Outcomes. AP-T141/10, 2010.

The examples above are a good illustration of how useful speed restrictions are in enforcing speed limits. If left untreated, the actual reduction in average speed after a "new" speed limit is introduced will usually be around ¼ of the difference between the "new" and previous limit (Elvik et al., 2009, Gaca and Kiec, 2005).
The less restrictive speed management measures include signs giving "recommended speeds" telling the drivers how fast they should go on a section. This will usually produce a speed reduction on average of 3.2 ÷ 5 km/h (FHWA, 2012).
As well as the less restrictive measures, physical traffic calming measures are also used. These are much more effective and include speed bumps and raised surfaces. International research (FHWA, 2012) suggests that speed bumps are highly effective and help to reduce vehicle speeds by about 32 km/h and about 27 km/h when speed tables are applied. Raised pedestrian crossings used as an obstacle produce results similar to speed bumps with average speed reductions by 4.0 ÷ 6.5 km/h. Please note, however, that while speed bumps reduce speed locally, speed increases in between the bumps which increases emissions (accelerating and braking is more frequent). This is why it makes more sense to use comprehensive traffic calming measures with speed reductions distributed evenly on a designated road section. Mini roundabouts and small roundabouts in place of regular junctions reduce average speed by 36 km/h and 54 km/h respectively.
The results make it very clear that speed management is most effective when physical traffic calming measures are used. Despite that, before any such treatment, an analysis should be conducted to look at the effectiveness of other measures such as active speed limit signs, intensive enforcement, adding or removing lines separating traffic lanes and allowing vehicles to be parked along the road. It is also important to remember that physical traffic calming measures cannot be used freely e.g. on main roads or roads frequently used by emergency services.

3. Research and results

Research into the effectiveness of speed management measures included accident and casualty analyses "before" and "after" a treatment (in locations where the date of a treatment was known). If the date of a treatment was not known, the trends in accident numbers were analysed. Surrogate safety measures were studied too, i.e. vehicle speeds. The research covered the following cases:

a) local speed limits (Figure 1a) – 44 locations for accident analysis and 27 locations for speed analysis
b) TEMPO 20 residential area (Figure 1b) – 10 locations for accident analysis and 8 locations for speed analysis
c) TEMPO 30 area speed limit (Figure 1c) – 35 locations for accident analysis and 12 locations for speed analysis
d) sections with mild traffic calming measures (change in vehicle trajectory while providing good passage for heavy vehicles, Figure 1d) – 33 locations for accident analysis and 29 locations for speed analysis
e) sections with additional sign to inform of a possible speed control on section (Figure 1e) – 30 locations for accident analysis and 12 locations for speed analysis.

Fig. 1.
Examples of analysed speed management measures

3.1. Speed analysis

Due to the conditions on site speed was measured using three measurement methods:

- manual (observations in the field in subsequent measurement cross-sections or analysis of recorded video),
- automatic (pneumatic detectors)
- a combination of manual and automatic measurements.

Manual measurements helped to determine vehicle speeds in free flow traffic only, split into two types of vehicles (light and heavy vehicles). The advantage of the method is that it is done without the drivers noticing. This method was used in Tempo 20 and Tempo 30 zones and in the case of local speed limits.

Automatic measurements helped to ensure that speed was recorded very accurately while differentiating between vehicle speeds in the entire traffic flow and in free flow traffic. The test devices were able to identify vehicle types. This method was used on sections with local speed limits, mild traffic calming measures and on speed control sections.

Speed was measured on sections with speed management measures and on control sections (with no speed management measures). In the case of area speed limits the control sections were selected on streets with Tempo 20 and Tempo 30 characteristics. Mild traffic calming measures were represented by results from sections of a similar characteristic (roadside, cross-section, accessibility). Untreated sections of the same road were also considered. Local speed limits and section control were represented by the following cross-sections: app. 150 m before the sign (as a control section), at the sign and behind it (app. 150 m). Control sections representing local speed limits had similar geometrical parameters. Table 4 lists the results of speed management effectiveness for speed reduction.

Table 4
Results of speed tests in free flow traffic on control sections and on treated sections

Speed management measure	**Control cross-section**				**Treated cross-section**				**Reduction**		
	Mean speed *V*	**85th percentile speed V_{85}**	**Speed variability *WZV***	**Share of those above the speed limit *UVd***	**Mean speed *V***	**85th percentile speed V_{85}**	**Speed variability *WZV***	**Share of those above the speed limit *UVd***	**Mean speed *V***	**85th percentile speed V_{85}**	**Speed variability *WZV***
	[km/h]	[km/h]	-	[%]	[km/h]	[km/h]	-	[%]	[km/h] [%]	[km/h] [%]	- [%]
Speed limit 40	64.4	75.5	0.185	45	60.0	69.7	0.173	89	4.4 6.8%	5.8 7.7%	0.012 6.5%
Speed limit 50	69.9	82.1	0.185	47	60.8	70.7	0.179	77	9.1 13.0%	11.4 13.9%	0.006 3.2%
Speed limit 60	82.3	97.0	0.174	24	70.4	80.7	0.152	81	11.9 14.5%	16.3 16.8%	0.022 12.6%
Speed limit 70	79.9	93.2	0.170	19	70.6	83.3	0.194	43	9.3 11.6%	9.9 10.6%	-0.024 -14.1%
Residential area (TEMPO 20)	38.0	45.5	0.203	77	32.9	40.5	0.237	95	5.1 13.4%	5.0 11.0%	-0.034 -16.7%
TEMPO 30	45.4	53.7	0.185	44	38.0	45.5	0.203	77	7.4 16.3%	8.2 15.3%	-0.018 -9.7%
Mild traffic calming measures	60.0	70.0	0.173	79	53.8	62.1	0.167	68	6.2 10.3%	7.9 11.3%	0.006 3.5%
Speed control sections	66.6	76.7	0.159	88	56.1	64.6	0.166	71	10.5 15.8%	12.1 15.8%	-0.007 -4.4%

The results in Table. 4 show that:

- local speed limits help to reduce average speed significantly compared to the control cross-section (no speed restrictions). The reduction depends on the limit and changes from app. 6.8% to 14.5% on treated sections;
- temporary speed enforcement signs help to reduce speed for longer compared to speed cameras. This measure reduces average speed by about 15.8% compared to the control section;
- mild traffic calming measures help to reduce average speed by about 10.3% with vehicle speeds becoming similar;
- while Tempo 30 zones help to reduce speed by app. 16.3% compared to control sections, the spread of speeds was quite strong with speeds depending on the local road conditions and environment;
- residential area (Tempo 20) results show a speed reduction by about 13.4% in free flow traffic compared to control sections. Just as with Tempo 30 zones, the spread of speeds was significant and depended on local road conditions. Please note the high percentage of drivers going above the speed limit in living areas.

3.2. Accident analysis

With limited data availability, the analysis of speed management effectiveness was simplified. The annual number of accidents and casualties was determined for all the locations under analysis from 2006 to 2014. The next step was to choose those locations whose date of treatment was known and fell within the period 2007 – 2013. Once selected, the locations were then analysed for their annual average road safety rates "before" and "after" the treatment. This produced the quotients of the "after"/"before" measures under estimation for the specific speed management measures. The lower the value of the quotient, the higher the effectiveness of the measure. This is a typical approach to "before" and "after" effectiveness evaluations. Because accidents may change regardless of the treatment, an additional comparison was made of the quotients to general accident trends in the regions under analysis. The effectiveness of the measures was estimated by comparing the "after" quotients to the "before" situations for the treated sites and control sections. The bigger difference between treated site and control section values, the more effective the treatment is (under the assumption that test site values are lower than those in control areas).

Table 5 lists the effectiveness indicators of the speed management measures and the resulting accident and casualty reduction. Grey boxes mean that the measure has had no positive effect. The other boxes mean better road safety as a result of a measure. Because residential areas have a low number of accidents (Tempo 20), those test sites were analysed together with Tempo 30 zones.

Table 5
Analysis of the effects of speed management on road safety

Speed management measure	CMF [-]							
	All accidents		Speed-related accidents		All serious injuries and fatalities		Speed-related serious injuries and fatalities	
	Treated group	Control group	Treated group	Control group	Treated group	Control group	Treated group	Control group
Speed limit	1.19	0.72	0.94	0.86	0.45	0.82	0.32	0.65
Residential area (TEMPO 20) and TEMPO 30	0.78	0.71	0.63	0.65	0.65	0.74	0.47	0.68
Mild traffic calming measures	0.87	0.62	0.75	0.59	1.00	0.58	1.12	0.60
Speed control sections	0.37	0.79	0.36	0.79	0.43	0.77	0.34	0.79

The results show that speed enforcement (signing of speed control section) and area speed limits are effective in improving road safety. It is important to note, however, that the results are based on a relatively small sample and more research is required.
With the evaluation of how different speed management measures affect road safety on Poland's lower class roads, it is clear that the effects differ from measure to measure. Using the results of "before" and "after" comparisons and taking account of the general road safety trends, the following are the initial evaluations of how the particular measures affect road safety:

- no positive effects were established in Tempo 20 and Tempo 30 zones on accident reduction. Fatalities and serious injuries, however, are down – the average reduction rate being 27%;
- contrary to expectations, mild traffic calming measures had no positive effect on accident reduction or casualty reduction;
- sections of roads with local speed limits have seen a positive effect of the restrictions with fewer accidents (a 19% reduction) and serious injuries and deaths (an 11% reduction);
- sections with speed limit enforcement measures have seen very positive effects both in terms of accidents (a 40% reduction) and serious injuries and deaths (a 42% reduction).

3.3. Power model calibration

The next step of the analysis was to calibrate the "a" parameter for the "power model" given in equation (1) using the speed results and accident analysis. The factors calculated include speed-related accidents, severity of all accidents and speed-related accidents which should have a strong relation to speed. Table 6 gives the parameter's values for the measures analysed. The "*a*" parameter for a local speed limits has not been evaluated because of insufficient accident sample for each value of speed limit.

Table 6
The "a" parameter in the "power model" equation based on authors' research

Speed management measure	Power model's *a* parameter		
	Speed-related accidents	Total serious injuries and fatalities	Speed-related serious injuries and fatalities
Speed limit	-	-	-
Residential area (TEMPO 20)	3.2	3.0	5.2
TEMPO 30	2.6	2.4	4.2
Mild traffic calming measures	2.6	0.0	-1.0
Speed control sections	6.0	4.9	6.3

4. Conclusion

The research into the effects of speed management measures on road safety shows that the measures have a varying effect on safety when measured with direct rates such as accidents and accident severity and with indirect rates such as vehicle speed.

As regards the less restrictive speed management measures, especially mild traffic calming measures, the results show that compliance is poor and the effect is low or non-existent when it comes to accidents and casualties. Speed enforcement is most effective as can be seen both from direct and surrogate measures. Area speed management (residential area, Tempo 30), especially when accompanied by physical speed reduction measures such as speed bumps or raised junctions is highly effective. When used outside the zones, however, the measures help to reduce speeds locally only.

Given the specificity of the research, the results are difficult to compare to other countries' results. Despite that, we can see that mild traffic calming measures in particular such as refuge islands or islands on entry to a town, are not as effective as in other countries. This may be the result of culture and sociology in general where regional or motorisation differences play a role. A review of those measures should be conducted and more research is required.

The results can be used to build "power models" that help to understand the effectiveness of speed management measures. This will ensure that proposed treatments will offer the best effectiveness for a given set of conditions.

References

Austroads Ltd.: Infrastructure/Speed Limit Relationship in Relation to Road Safety Outcomes. AP-T141/10, 2010.

Cameron, M.H.; Elvik, R. 2010. Nilsson's Power Model connecting speed and road trauma: Applicability by road type and alternative models for urban roads, *Accident Analysis and Prevention*, 42: 1908-1915.

CMF Crash Modification factors Clearinghouse. Available from Internet: <http://www.cmfclearinghouse.org/resources_hsm.cfm>.

Elvik, R.; Hoye, A.; Vaa, T.; Sorensen, M. 2009. *The Handbook of Road Safety Measures*. Emerald Group Publishing, The second edition.

Federal Highway Administration: Speed Management: A Manual for Local Rural Roads Owners. FHWA-SA-12-027, U.S. Department of Transportation, 2012.

Gaca, S. 2002. *Badania prędkości pojazdów i jej wpływu na bezpieczeństwo ruchu drogowego (Research on speed of vehicles and its effect on road safety)* Zeszyty Naukowe PK - Inżynieria Lądowa vol. 75. Politechnika Krakowska.

Gaca, S.; Kiec, M. 2005. Badania reakcji kierujących pojazdami na zmianę ograniczenia prędkości na terenach zabudowy (The study on reaction of drivers to change the speed limit in built-up areas), *Transport Miejski i Regionalny (Urban and Regional Transport)*, 12: 9-14.

Highway Safety Manual (HSM). AASHTO, Washington DC, 2010.

COMPARISON OF SELECTED IMPACT PARAMETERS BY SIDE VEHICLE CRASH TESTS WITH COMPUTATIONAL SOFTWARE RESULTS

Stanislav Tokař[1], Marek Semela[2], Martin Bilík[3], Albert Bradáč[4]
[1,2,3,4] *Institute of Forensic Engineering, Brno University of Technology, Brno, Czech Republic*

Abstract: Article shows carried out crash tests between front part of moving and side part (cabin for passengers) of stationary vehicle. The goal of the article was to investigate and observe as many impact parameters as possible, which are necessary for correct traffic accident analysis. Authors carried out experiments with impact speeds of impacting vehicle between 36 and 55 kph. Emphasis was put on investigation of post-crash motion, depth of deformations on vehicles and amount of deformation energy as the parameters for accident reconstructionist. The amount of deformation energy has been compared to results for impacting vehicle gained from CRASH3 module calculation in software PC-CRASH ver. 10.2 and also with simulations with the help of simulating software Virtual CRASH ver. 3.0. Sufficient results correlation at comparable tests between those methods has been found.

Keywords: side crash test, impact parameters, energy equivalent speed, deformation energy.

1. Introduction

The issues dealt with in this article fall within forensic science, particularly within traffic accident reconstruction. Experts who within the framework of a complex analysis of a traffic accident often use simulation programs such as PC Crash (2016) and Virtual CRASH (2016) in order to process the actual plot of the accident must always enter only those input parameters that are in a technically acceptable range. For the verification of the collision parameters in particular it is necessary to use the data from the real crash tests performed for such needs. The works (Campbell, 1974), (Strohrer, 1986), (Batista, 2005) (Seiffert, 2007) and (Cichos, 2008) deal in detail with the issue of sought parameters such as force, energy intensity of impact, stiffness of a given part of a vehicle or vehicle deformation depth. These obtained parameters are subsequently used in traffic accident reconstructions. Many authors and publications such as (Burg, 2009), (Branch, 2011), (Huang, 2002) and (Hugemann, 2007) deal with traffic accident reconstruction that aims to find out the cause of an accident.

The work focuses on side crash tests, when a passing vehicle crashes into the side of a stationary vehicle. All the principal world organisations dealing with safety research and vehicle testing (EuroNCAP, 2016; NHTSA, 2016; IIHS, 2016) have included similar impact configurations in their testing programmes. Euro NCAP as the European independent testing authority uses a deformable barrier running at a speed of 50 kph as a “ram” which crashes into the side of a tested vehicle at an angle of 90°. The ram has a weight of 950 kg as well as a front deformable honeycomb panel size of 500 x 1500 mm (height x width). The organisation called National Highway Traffic Safety Administration (NHTSA) tests the side of vehicles by impact at an angle of 90° which is caused by a deformable barrier running at a speed of 61 kph. The ram’s weight is 1507 kg and its front part has a height of 600 mm. Insurance Institute of Highway Safety (IIHS) performs two different vehicle side tests. The first impact test is coincident with the NHTSA organisation if, and only if, a higher moving deformable barrier of at least 760 mm in height is used. This higher barrier corresponds better to higher front parts of vehicle, in particular to SUVs. The second test (performed by NHTSA as well) differs in mutual impact configuration when a tested stationary vehicle is turned at an angle of 27° towards the longitudinal axis of the moving deformable barrier. The barrier has a weight of 1360 kg and crashes at a speed of 61 kph.

The above-mentioned list of performed side crash tests is focused on the research and testing of safety of new vehicles introduced to the market. The possibility of injury to the crew members of these vehicles, who are replaced with dummy figures during testing, is the main sought parameter. The publication (Chan, 1998) focuses on a correlation between the penetration depth of a part of the vehicle body into its interior – DEPTH, the Thoracic Trauma Index TTI and Pelvic Lead. The work (Stolinski, 1998) concentrates on investigation into the possibility of injury to the vehicle crew in case the impact occurs at a side of the vehicle more distant from the passenger position.

During four performed proper crash tests the vehicles were not fitted with dummy figures and the main attention was therefore focused on investigation into the impact parameters of the vehicles themselves. In particular, they include post-impact velocity, post-impact movement (trajectory), post-impact deceleration and subsequent calculation of deformation energy of vehicle collision and its redistribution to individual vehicles. The deformation energy acting on individual vehicles was quantified by energy equivalent speed (EES).

The performed crash tests were carried out using older vehicles more or less affected by bodywork corrosion. Corrosion significantly reduces the stiffness of vehicle bodywork and larger deformations therefore rationally occur at the same parameters. Such deformations would result in more serious injury to the crew of such a vehicle than to the crew of a new vehicle. However, this fact may not be entirely wrong, especially once we realize that for example in Germany the average age of a vehicle is from eight to nine years; nevertheless, in the Czech Republic it already ranges from fourteen to fifteen years.

[1] Corresponding author: stanislav.tokar@usi.vutbr.cz

The investigation thus aimed to perform crash tests, analyse obtained data and on the basis of this data determine the EES parameter for individual vehicles. It further aimed to compare obtained data with the computational solution carried out using CRASH3 module in PC CRASH version 10.2 simulation program on the basis of comparable vehicle stiffness database and also to apply obtained data and verify it by means of simulation with support of Virtual CRASH version 3.0 simulation program.

2. Methods

In total, four crash tests within an impact speed range of 36 to 55 kph were performed. It was always a collision of the front part of a moving vehicle with the side of a stationary vehicle at an angle of 90°: during crash test no. 3 there was a mutual angle between the vehicles of about 83° whereas during crash test no. 1 the mutual angle between the vehicles was ca. 94°. In two cases (tests no. 1 and 2) the Honda Civic was used as a stationary vehicle. During crash tests no. 3 and no. 4 Skoda Felicia, or Skoda Felicia Combi, was used as a running vehicle. Therefore even from this perspective an appropriate comparison of damage range to vehicles of the same type is possible at different parameters. The performed crash tests were carried out with the participation of an IFE team for the following vehicle impact configurations:

1. A Nissan Almera crashed into the side of a stationary Honda Civic at a speed of ca. 55 kph,
2. A Chrysler Sebring crashed into the side of a stationary Honda Civic at a speed of ca. 43 kph,
3. A Skoda Felicia Combi crashed into the side of a stationary Mercedes Benz at a speed of ca. 50 kph,
4. A Skoda Felicia crashed into the side of a stationary Opel Omega Combi at a speed of ca. 36 kph.

Fig. 1.
Side crash test between Nissan Almera (moving vehicle) and Honda Civic, 3D scan in final position

The determination of deformation energy absorbed by the deformation zones of a vehicle during a collision with an obstacle (or another vehicle) is one of the important parameters in the solution of vehicle collision itself. The entire movement of vehicles during the plot of an accident depends on this amount, particularly the calculation of the driving speed of vehicles just before collision. In an expert's practice the only clue to determining the deformation energy is the range of vehicle damage or the deformation depth of its relevant sections. If we knew the stiffness characteristics of the relevant sections of particular vehicles, we could determine the consumed deformation energy on the basis of a relationship:

$$E_D = \frac{1}{2} \cdot k \cdot x^2 \tag{1}$$

Where; E_D: deformation energy [J], x: deformation depth [m], k: car stiffness [N/m].
Unfortunately, the stiffness characteristics are not commonly available for reconstructionist. In an expert's practice the expert estimate of EES, which expresses kinetic energy of a vehicle proportional to the deformation energy that is needed to reach an appropriate range of permanent deformation. This article should serve for verification of these estimates, while, on the contrary, the consumed deformation energy, or EES of the vehicles, will be determined from the input parameters. During the actual process of determination of the deformation energy during vehicle collision we will proceed from the law of the conservation of energy, therefore the (vehicle) system energy before collision must be equal to the total system energy after collision. In vehicle collision mechanics three types of energy are distinguished:

$$E_P = m \cdot g \cdot h \tag{2}$$

$$E_{K_T} = \frac{1}{2} \cdot m \cdot v^2 \tag{3}$$

$$E_{K_R} = \frac{1}{2} \cdot I \cdot \omega^2 \tag{4}$$

$$E_D = W_D = \frac{1}{2} \cdot m \cdot EES^2 \quad (5)$$

Where; E_P: potential energy [J], E_{KT}: kinetic energy of translation [J], E_{KR}: rotation energy [J], E_D: deformation energy [J] which is determined by performing deformation work W_D, m: vehicle weight [kg], g: acceleration due to gravity value [m/s^2], h: vehicle centre height [m], v: vehicle speed [m/s], ω: vehicle angular velocity [rad/s], I: vehicle moment of inertia [kg.m^2], EES: energy equivalent speed [m/s].
The total energy balance of a vehicle colliding with an obstacle (vehicle) is therefore as follows:

$$\sum_{i=1}^{n} (E_{K_T i} + E_{K_R i} + E_{pi}) = \sum_{i=1}^{n} (E'_{K_T i} + E'_{K_R i} + E'_{Pi}) + \sum_{i=1}^{n} E_{Di} \quad (6)$$

Where; E_{KTi}, E_{KRi}, E_{Pi} :individual components of the ith vehicle (obstacle) energy before collision [J], E'_{KTi}, E'_{KRi}, E'_{Pi} :individual components of the ith vehicle (obstacle) energy after collision [J], E_{Di}: deformation energy of the ith vehicle (obstacle) [J].
From the total energy balance, we are able to determine the total deformation energy consumed for documented permanent vehicle damage cause. For simplification, the components of energy converted into heat energy are not taken in account. In the instance that we know the EES value for one vehicle it is possible from the following two equations - after the mathematical treatment on the basis of known depths of deformation to individual vehicles - to divide the deformation energy expressed for each vehicle in the EES form:

$$E_{Def} = \frac{1}{2} \cdot m_A \cdot EES_A{}^2 + \frac{1}{2} \cdot m_B \cdot EES_B{}^2 \quad (7)$$

With the use of the following equation we can, after the mathematical treatment and substitution method (7), obtain the division of the total deformation energy into deformation energy components for individual vehicles, for instance, on the basis of known depths of deformation to individual vehicles. For this method the vehicles should have preferably the same or at least similar bodywork stiffness characteristics in the area of collision.

$$\frac{EES_A}{EES_B} = \sqrt{\frac{m_B \cdot x_A}{m_A \cdot x_B}} \quad (8)$$

The data acquired from the performed crash tests was processed by three methods:

I. The determination of EES on the basis of deformation depth: the total deformation energy was calculated from the discovered parameters of vehicle impact and post-impact vehicle movement. This total deformation energy was divided into components for individual vehicles on the basis of known deformation depths. This method for chosen collisions is not entirely appropriate as it is the collision of the front part of the vehicle (with higher stiffness) into the side of the vehicle. It is appropriate to compare even those results achieved by this procedure in order to find out whether there will be any noticeable difference in older vehicles or not,
II. The determination of EES on the basis of stiffness parameters available from CRASH3 software data: when the stated EES values for moving vehicles were acquired from the database of vehicle stiffness parameters available in CRASH3 software, which is a part of PC Crash ver. 10.2 simulation program. Subsequently, on the basis of the known EES value for a moving vehicle and the total deformation energy values of a given collision the EES value of the second (stationary) vehicle was calculated with the help of the equation (7),
III. Vehicle impact simulation with the simulation program support: the data acquired from the performed crash tests were subsequently used for the vehicle impact simulation with the simulation program support. In this case Virtual CRASH ver. 3.0 simulation program was used for traffic accident reconstruction. Simulation of the vehicle impact and post-impact vehicle movement is carried out by means of gradual optimization of the input values. The impact simulation is carried out by means of forward methods, i.e. from the centre to the final position. The program uses for impact solution the so-called impulse-impact model which replaces all the contact forces acting in the deformed profile of the damaged part of the vehicle with a single force resultant passing through so called point of impact. On the basis of the position of the point of impact from the profiles of both vehicles in the moment of maximum deformation depth in a direction of impulse action the energy equivalent speed (EES) values are recalculated from the deformation energy.

3. Results

Individual crash tests and the acquired data, which was subsequently used for the determination of the EES parameter for individual vehicles, are described in this chapter.

3.1. Crash test no. 1 – Nissan Almera x Honda Civic

This crash test was carried out by the collision of a Nissan Almera running at a speed of 55 kph that crashed with its front part into the left side of a stationary Honda Civic. The angle of longitudinal axes of the vehicles was ca. 94°, see fig. 2. The parameters of the vehicles as well as the impact and post-impact movement necessary for the actual solution and calculation of deformation energy are stated in table 1. The breaking of the Nissan was taken into account for the post-impact movement. The post-impact rotation of the Honda vehicle was of an angle of ca. 34°. The post-impact movement of the Honda vehicle was taken as friction (skidding) over the surface (dry, clean asphalt).
In order to calculate the EES value for the Nissan Almera vehicle in CRASH3 program, the input parameters for recalculation chosen were the values from the crash test of a similar vehicle Nissan Sentra model year 1998, test number 2771, carried out by NHTSA.
For simulation the Virtual CRASH version 3 simulation program was used by i.a. Kudlich-Slibar impact model. A certain simplification occurs with this model – all the impact plot is situated in one moment of time and the impact forces are replaced with their resultant passing through the so-called point of impact. The input parameters were:

- Vehicle positions in the moment of the first contact (i.e. Exact point of contact and a mutual angle of rotation of the longitudinal axes of vehicles),
- Vehicle movement speeds just before impact,
- Angular speeds,
- Immediate vehicle weight,
- Size parameters of vehicle (according to the manufacturer),
- Adhesion (just for the conformity of vehicle runs to the final positions – does not affect the impact calculation),
- Deformation depth.

In order to reach conformity the collision parameters were varied:

- Impact point position (x,y,z),
- Restitution coefficient.

It was not necessary to vary the other impact parameters (friction, impact plane direction) as it was an impact completely without slide and therefore with a low impact point speed during collision.

Table 1
Parameters of impact and post impact motion of vehicles - Test no. 1 (author)

Nissan Almera (A) Length: 4340 mm; Width: 1690 mm; Height: 1395 mm	**Honda Civic (B)** Length: 4325 mm; Width: 1695 mm; Height: 1390 mm
Vehicle weight (m_A) = 1050 kg	Vehicle weight (m_B) = 1100 kg
Pre-impact speed (v_A) = 54,8 kph	Pre-impact speed (v_B) = 0 kph
Post-impact trajectory (S'_A) = 3,75 m	Post-impact trajectory (S'_B) = 4 m
Post-impact speed (v'_A) = 25,2 kph	Post-impact speed (v'_B) = 27,6 kph
Deformation depth (x_A) = 0,26 m	Deformation depth (x_B) = 0,25 m
Total deformation energy (E_D) ca. 61 kJ	

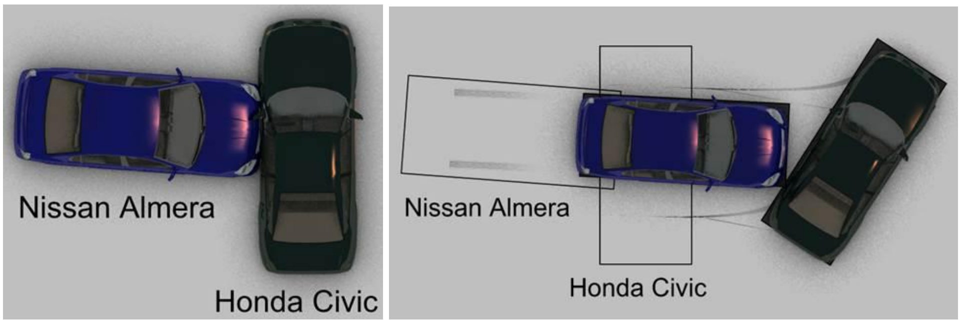


Fig. 2.
Side crash test no. 1, left – impact position, right – final position (Virtual CRASH)

3.2. Crash test no. 2 – Chrysler Sebring x Honda Civic

The crash test was carried out with a Chrysler Sebring vehicle running at a speed of 43 kph, which crashed with its front part into the left side of a stationary Honda Civic vehicle at an angle of 90° (see fig. 3). After the collision of vehicles the anticlockwise rotation of the Honda vehicle at an angle of ca. 90° took place, the vehicles subsequently got mutually wedged with their left sides and this way moved to their final positions.

In the calculation of the EES value for the Chrysler Sebring vehicle in CRASH3 program the input parameters for recalculation chosen were the values from crash test of similar vehicle Chrysler Sebring model year 2007, test number 5886 carried out by NHTSA.

Table 2
Parameters of impact and post impact motion of vehicles - Test no. 2 (author)

Chrysler Sebring (A) Length: 4844 mm; Width: 1792 mm; Height: 1394 mm	**Honda Civic (B)** Length: 4325 mm; Width: 1695 mm; Height: 1390 mm
Vehicle weight (m_A) = 1510 kg	Vehicle weight (m_B) = 1100 kg
Pre-impact speed (v_A) = 43 kph	Pre-impact speed (v_B) = 0 kph
Post-impact rotation (α'_A) = 0 °	Post-impact rotation (α'_B) = 90 °
Post-impact speed (v'_A) = 25 kph	Post-impact speed (v'_B) = 25 kph
Deformation depth (x_A) = 0,10 m	Deformation depth (x_B) = 0,20 m
Total deformation energy (E_D) ca. 44 kJ	

Fig. 3.
Side crash test between Chrysler Sebring (moving vehicle) and Honda Civic (author)

3.3. Crash test no. 3 – Skoda Felicia Combi x Mercedes Benz W210

The Skoda Felicia Combi vehicle crashed with its front part into the right side of Mercedes Benz W210 vehicle at a speed of 50,5 kph. The angle between longitudinal axes of the vehicles during the collision was ca. 83, see fig. 4. After the collision of vehicles, an anticlockwise rotation of the Mercedes Benz vehicle at an angle of ca. 30 ° took place.
In the calculation of the EES value for the Skoda Felicia vehicle in CRASH3 program, the input parameters for recalculation chosen were the values from crash test of similar vehicle Volkswagen Golf II model year 1986, test number 945 carried out by NHTSA.

Table 3
Parameters of impact and post impact motion of vehicles - Test no. 3 (author)

Skoda Felicia Combi (A) Length: 4237 mm; Width: 1635 mm; Height: 1420 mm	**Mercedes Benz W210 (B)** Length: 4818 mm; Width: 1799 mm; Height: 1441 mm
Vehicle weight (m_A) = 900 kg	Vehicle weight (m_B) = 1510 kg
Pre-impact speed (v_A) = 50,5 kph	Pre-impact speed (v_B) = 0 kph
Post-impact trajectory (S'_A) = 1,7 m	Post-impact trajectory (S'_B) = 2,2 m
Post-impact speed (v'_A) = 15 kph	Post-impact speed (v'_B) = 21 kph
Deformation depth (x_A) = 0,26 m	Deformation depth (x_B) = 0,25 m
Total deformation energy (E_D) ca. 53 kJ	

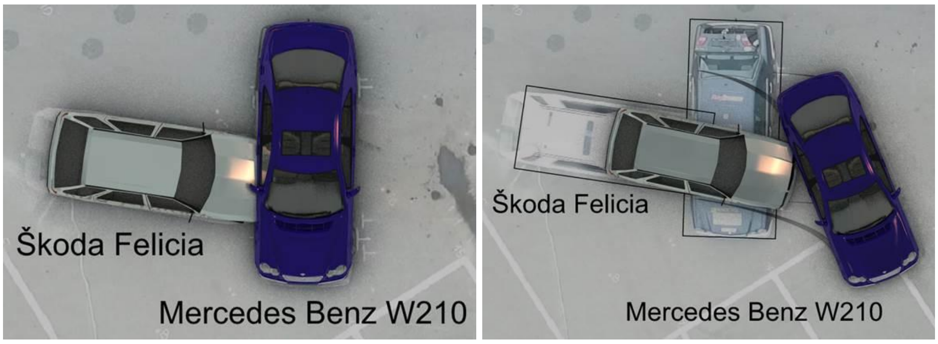


Fig. 4.
Side crash test no. 3, left – impact position, right – final position (Virtual CRASH)

3.4. Crash test no. 4 – Skoda Felicia x Opel Omega Combi

The Skoda Felicia vehicle crashed with its front part into the right side of Opel Omega Combi vehicle at a speed of 36 kph. The angle between longitudinal axes of the vehicles during the collision was ca. 90° (see fig. 4). After the collision of the vehicles no significant rotation of the Opel vehicle took place; it was therefore neglected in the solution of energy balance.
In the calculation of the EES value for the Skoda Felicia vehicle in CRASH3 program the input parameters for recalculation chosen were the values from the crash test of a similar vehicle, the Volkswagen Golf II model year 1986, test number 945 carried out by NHTSA.

Table 4
Parameters of impact and post impact motion of vehicles **-** *Test 4 (author)*

Skoda Felicia (A) Length: 3883 mm; Width: 1635 mm; Height: 1415 mm	**Opel Omega Combi (B)** Ĺenght: 4898 mm; Width: 1776 mm; Height: 1505 mm
Vehicle weight (m_A) = 925 kg	Vehicle weight (m_B) = 1750 kg
Pre-impact speed (v_A) = 36,3 kph	Pre-impact speed (v_B) = 0 kph
Post-impact trajectory (S'_A) = 1,1 m	Post-impact trajectory (S'_B) = 1,3 m
Post-impact speed (v'_A) = 12 kph	Post-impact speed (v'_B) = 15 kph
Deformation depth (x_A) = 0,20 m	Deformation depth (x_B) = 0,10 m
Total deformation energy (E_D) ca. 26 kJ	

4. Discussion

The achieved results are laid out in a well-arranged way in Table 5. The EES parameter value for individual vehicles was inacceptable accordance with the chosen methods (deviations found in system of kph units). In almost all tests the calculated EES value for moving vehicle was higher in the method II. This phenomenon would correspond with the higher stiffness of the front part of vehicle against the side. Nevertheless, the difference is not too significant as with regard to the condition of bodywork of individual vehicles, particularly with regard to the range and degree of corrosion the stiffness of those parts could be already considerably affected (reduced). Deformations of the same or similar vehicles from particular crash tests are shown and compared in fig. 5 – 7. By means of simulation in Virtual CRASH program a good accordance between calculated parameters and parameters recorded in real crash test was confirmed. It is possible to use further the obtained results in an expert's practice in traffic accident reconstruction, particularly when determining the EES value.

Fig. 5.
Side part of Honda Civic, left – test no. 1 EES cca 27 kph, right – test no. 2 EES cca 25 kph (author)

Fig. 6.
Front part of Skoda Felicia, left – test no. 3 EES cca 28 kph, right – test no. 4 EES cca 23 kph (author)

Fig. 7.
Side part of vehicle, left Mercedes Benz – test no. 3 EES cca 22 kph, right Opel Omega Combi – test no.4 EES cca 10 kph (author)

Table 5
Overview of results according to the selected methods (author)

Test number	Impact speed [kph]	Deformation energy E_D [kJ]	Car	EES [kph]		
				I.	II.	III.
1.	55	61	Nissan	28	31	27
			Honda	27	23	27
2.	43	41	Chrysler	16	19	16
			Honda	26	24	25
3.	50	53	Skoda	28	28	26
			Mercedes Benz	21	21	23
4.	36	26	Skoda	22	24	22
			Opel	11	9	11

Acknowledgements

To conclude, authors of this article would like to express their thanks to all colleagues and collaborating experts, who helped with the arrangement of performed crash tests. They would also like to thank the Kovosteel Recycling Ltd., Czech police and Czech Technical University in Prague (CTU) for provision of vehicles, space and potential measuring and documenting technology.

References

Batista, M. 2005. A Note on Linear Force Model in Car Accident Reconstruction. In ARXIV: eprint arXiv: physics/0511127. Ithaca: Cornell University. Available from Internet: <http://arxiv.org/abs/physics/0511127v3>.
Branch, R. M.; Branch, R. 2011. *Vehicle accident analysis and reconstruction methods*. 2. edition, SAE International, Warrendale, U.S.A.
Burg, H.; Moser, A. 2009. *Handbuch Verkehrsunfallrekonstruktion: Unfallaufnahme, Fahrdynamik, Simulation*. 2. edition. Vieweg Teubner, Wiesbaden, Germany.
Campbell, K.L. 1974. *Energy Basis for Collision Severity*. SAE Technical Paper 740565, 1974, doi:10.4271/740565.
Chan, H.; Hackney, J.R.; Morgan, R.M.; Smith, H.E. 1998. An Analysis of NCAP Side Impact Crash Data. In *Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*.
Cichos, D. 2008. Crash Analysis Criteria Description. Bergisch Gladbach: Workgroup Data Processing Vehicle Safety. 156 p. Available from Internet: <http://www.crash-network.com/CrashAnalysisCriteria_2.1.1.pdf>.
Coufal, T.; Semela, M. 2016. Determination of Selected Crash Parameters in Head- on Vehicle Collision with Rollover. *PROMET– Traffic & Transportation*, 28(1): 81-89.
EuroNCAP 2016. European New Car Assessment Programme. Available from Internet: <http://www.euroncap.com/en>.
Huang, M. 2002. *Vehicle crash mechanics*, CRC Press, Boca Raton, U.S.A.
Hugemann, W. 2007. *Unfallrekonstruktion*, Autorenteam, Münster, Germany.
IIHS 2016. Insurance Institute of Highway Safety – an independent, nonprofit scientific and educational organization dedicated to reducing the losses-deaths, injuries and property damage-from crashes on the nation's roads. Available from Internet: <www.iihs.org>.
NHTSA 2016. National Highway Traffic Safety Administration–dedicated to achieving the highest standards of excellence in motor vehicle and highway safety. Available from Internet: <www.nhtsa.gov>.
PC Crash 2016. Version 10.2 – Software for traffic accident reconstruction and modelling. Available from Internet: <http://www.dsd.at/index.php?option=com_content&view=article&id=76:pc-crash&catid=37&Itemid=207&lang=en>.
Seiffert, U.; Wech, L. 2007. *Automotive safety handbook- 2 edition*, SAE International Warrendale, U.S.A.
Stolinski, R.; Grzebieta, R.; Fields, B. 1998. Side Impact Protection – Occupants in the Far-Side Seat, *International*

Journal of Crashworthiness, 3(2): 93-122.
Strohrer, C.H.E.; Wolley, R.L.; James, M.B. 1986. *Crush energy in accident reconstruction*, SAE International, Warrendale, U.S.A.
Virtual CRASH 2016. Version 3.0–Software for traffic accident reconstruction and modelling. Available from Internet: <www.vcrash3.com>.

EVALUTION OF TRAFFIC ACCIDENTS HAPPENING IN RECENT YEARS IN TURKEY

Muhammed Yasin Çodur[1], Ahmet Ünal[2], Ahmet Atalay[3]
[1,2] *Erzurum Technical University, Engineering and Architecture Faculty, Department of Civil Engineering, Erzurum, Turkey*
[3] *Atatürk University, Narman Vocational High School, Erzurum, Turkey*

Abstract: Throughout the world, in traffic accidents many people get injured or die. Even though the developed countries are able to find a partial solution to this problem, such a case continues to be a major problem in undeveloped countries. The number of traffic accidents in Turkey is increasing depending on the increase in the number of motor - vehicles. However, there may be different reasons for the increment of the number of traffic accidents. Countries are seeking a variety of methods to reduce the frequency of traffic accidents. One of the effective methods to reduce the casualty number of traffic accidents is the construction of divided highways. In this study, common traffic accidents happening in Turkey were evaluated and their causes and measures to be taken to reduce their frequency are investigated.

Keywords: traffic accidents, analyzes, deaths, casualty, traffic law.

1. Introduction

The first motor vehicle accident in England happened in 1896, when Bridget Driscoll, a pedestrian, was hit by a car in London while it was in 1910 when the same thing happened in Beşiktaş, Istanbul, Turkey. Fortunately, the pedestrians were only injured in the accident (Mason and Purde, 2000). World Health Organization estimates that traffic accidents resulting in death will be the 7th leading cause of all deaths in the world by 2030 (WHO, 2015). The world population increased %1.18 last year. The population growth rate was %1.5 in Turkey in 2015. Turkey's population was 78.741.053, the number of vehicles was 19.994.472 by the end of 2015 (Wikipedia, 2015). Highway traffic is the main component of transport facilities in the country. The population growth all over the world has led to increased transportation needs. Due to transportation needs there are more vehicles on highways, thereby increasing the number of injuring and fatal traffic accidents, which was counted in 2015 to be 1.313.359 in 2015.
Several studies from various parts of the world have been conducted on various aspects of traffic accidents beginning mainly from mid – 1960s. In the following years, studies were carried out on traffic accidents, one of the first of which is that developed by Smeed who examined 20 different countries traffic data by considering the relationship between death, population and the number of vehicles (Smeed, 1949). On the other hand, Andreassen developed Smeed's model using different long term data since he wanted to make comments based on not a single year (Andreassen, 1985). Miaou and Harry (1993) studied the statistical properties of four regression models and two Poisson regression models in terms of their ability to model vehicle accidents and highway geometric design relationships. Kim et al. (1995) enhanced a log-linear model to classify the influence of driver characteristics and behaviors in the casual sequence conducive to more severe injuries. Mussone et al. (1999) benefited from neural networks to analyze vehicle accident happening at intersections in Milan, Italy. Abdelwahab and Abdel-Aty (2001) investigated the accident data belonging to 1997 for the central Florida area. In Turkey, studies on traffic accidents have newly been conducted. Hazardous locations were determined on Isparta-Antalya-Burdur highway through Geographical Information System (GIS) by Karaşahin and Terzi (2003). Traffic accidents were analyzed by Üstündağ and Duran (2009) using GIS in Elazığ city. Atalay and Tortum (2010) analyzed traffic accidents happening between 1977 and 2006 in Turkey. Traffic accidents were analyzed using web-based GIS (Durduran et al., 2011). Tortum et al. (2011) studied clustering analysis of the districts in Erzurum for traffic accidents between 2002 and 2007. Çodur and Tortum (2012) developed traffic accident prediction model with neural network. Kabakuş et al. (2012) evaluated traffic accidents happening in provincial districts of Erzurum using GIS. Çodur (2012) studied traffic accident prediction models: applications for surrounding highways of Erzurum. Tortum et al. (2012) modelled traffic accidents in Turkey using linear regression analysis. Çodur et al. (2013) studied Erzurum north ring road accident prediction model with generalized linear regression. Atalay et al. (2013) modelled clustering analysis of the provinces in Turkey according to traffic accidents in 2011. Çodur et al. (2013) studied Erzurum north ring road accident prediction model with artificial neural network. Çodur et al. (2013) studied Erzurum- Tortum road accident prediction model with generalized linear regression. Atalay et al. (2013) analyzed temporal traffic accidents. Atalay et al. (2013) modelled traffic accidents by using geographical weighted regression analysis. Çodur and Tortum (2013) studied Erzurum-Pasinler road traffic accident prediction model. Atalay et al. (2014) modelled traffic accidents by using factor analysis. Çodur et al. (2015) analyzed GIS aided traffic accident. Çodur and Tortum (2015) studied an artificial neural network model for highway accident prediction: a case study of Erzurum. Tortum et al. (2015) analyzed traffic accidents in Erzurum province and its districts through GIS.
In this study, traffic accidents happening in Turkey over the last years were analyzed investigating the effective factors on traffic accidents. Daily and monthly distribution of traffic accidents was analyzed taking the reasons into consideration for the differences between the values. In addition, based on the distribution data, measures to reduce traffic accidents were also evaluated and some suggestions were proposed especially for drivers' faults.

[1] Corresponding author: mycodur@erzurum.edu.tr

2. Case study area

Turkey is a Eurasian country located in the territories of two continents (Figure 1), Asia (97% so-called Anatolia) and Europe (3% so called Thrace). . Wide footprint of the mountains in Turkey is one of the main factors that make all types of transportation difficult. Highway transportation began to be used widely in Turkey and after especially 1950s, when number and use of motor vehicles also increased. Today, the length of existing road has reached around 65,000 km in the country (Table 1).

Fig. 1.
Location of Turkey
Resource: General Directorate of Turkish Highways

Table 1
Lengths of international roads in Turkey by the end of the 2015
Resource: General Directorate of Turkish Highways

International Roads in TURKEY	TOTAL (Km)
Trans European Motorway	6940
E Roads	9353
BSEC Roads	4472
ECO Roads	9987
ESCAP Roads	5247
TRACEGA Roads	8365
Pan-European Corridors	261
EATL	5563

Modern Turkish Republic was inherited 18.365 km long road network from Ottoman State and during the first years of the Republic (beginning from 1923), great priority was given to the construction of the railways until 1950s. Even though such a policy preference prevented the development of highway network, after 1950s a new era was opened for Turkey's highway development history with the establishment of General Directorate of Turkish Highways on March 1st 1950. Turkey at present covers a total of 2.159 - km motorways, 31.213 km state roads consisting of 14.393 km asphaltic concrete, 16.399 km surface treatment, 71 km stone block, 45 km stabilized, 17 km earthen road and 288 km primitive roads. Provincial roads consist of 33.065 km road network covering 2.702 asphaltic concrete, 27.327 km surface treatment, 699 km stabilized, 614 km earthen road, 191 km stone block and 1.532 km primitive roads.

3. Results

The number of the traffic accidents was reported to be 1.228.928 in 2011 reaching up 1.313.359 in 2015 while the ratio of the traffic accidents to the total number of motor vehicles was 0,076 in 2011 reaching down 0.065 in 2015. The number of traffic accidents in the last five years is shown in Figure 2.

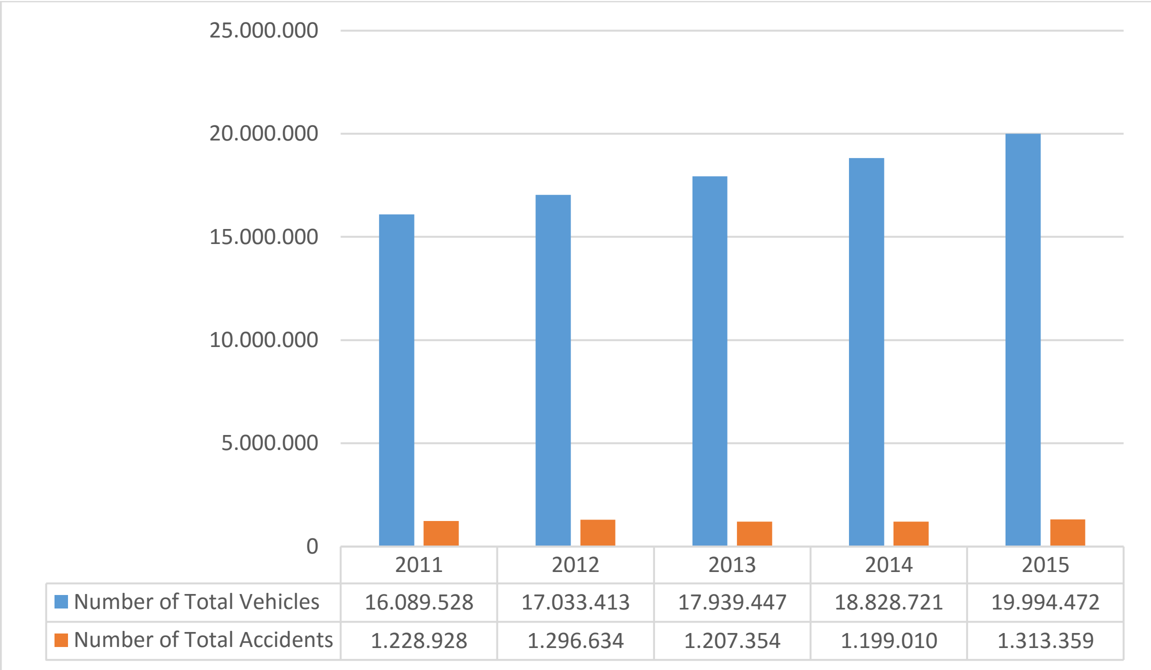
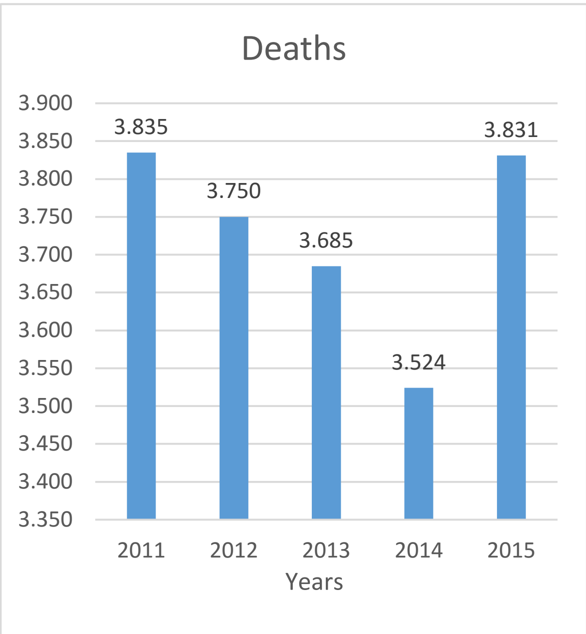
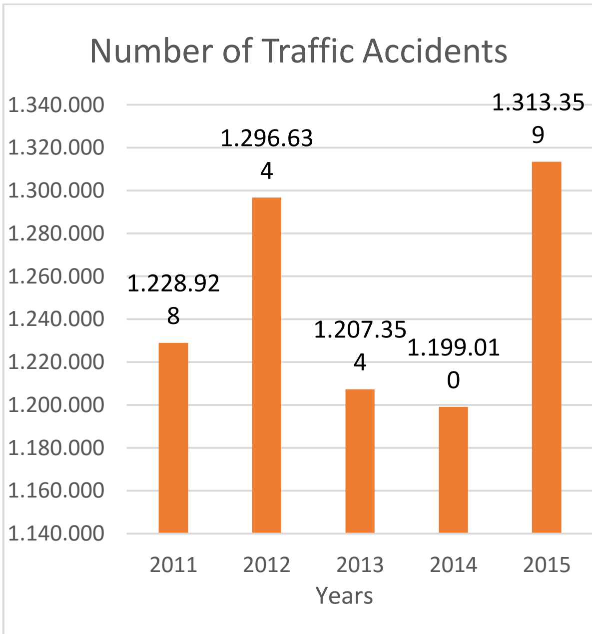


Fig. 2.
Number of traffic accidents
Source: Turkish Statistical Institute





(a)
Deaths in Traffic Accidents *(b) Number of*
Total Traffic Accidents

Fig. 3.
Yearly distribution of deaths in traffic accidents in Turkey
Source: Turkish Statistical Institute

Generally, there is a decrease in deaths in traffic accidents. It can be said that construction of divided highways and raising the standard of highways caused death rates to decrease. As another factor, the reduction of the number of people killed in traffic accidents can be shown to have been conscious of people in traffic accidents. Lengths of divided roads in the last five years are given in Figure 4.

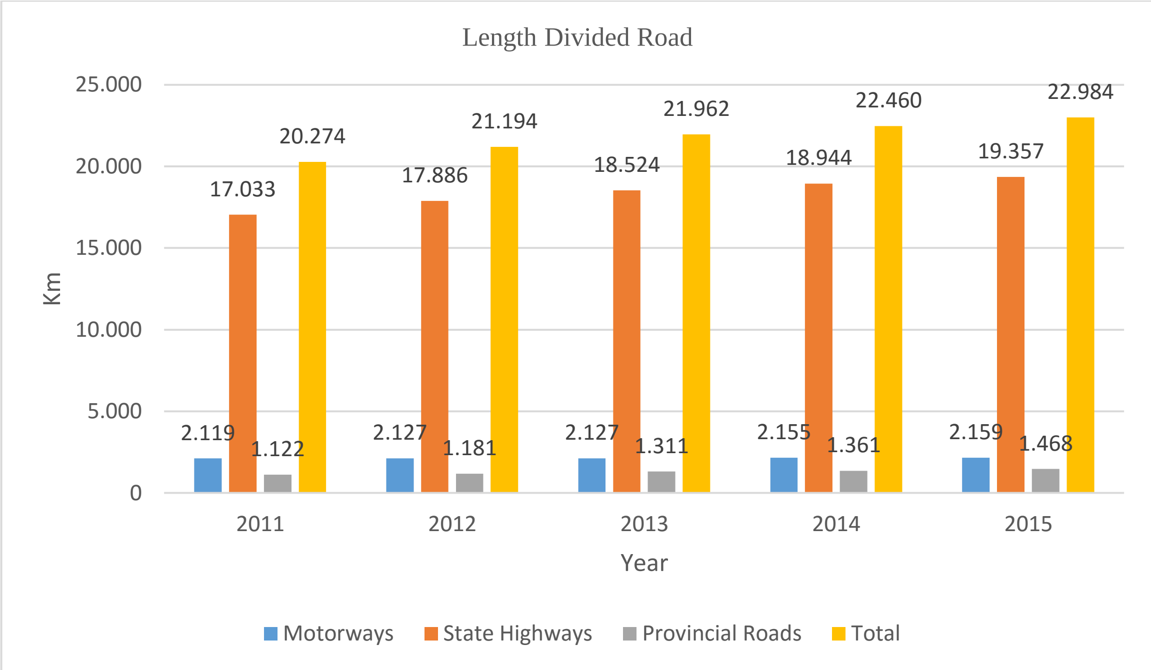
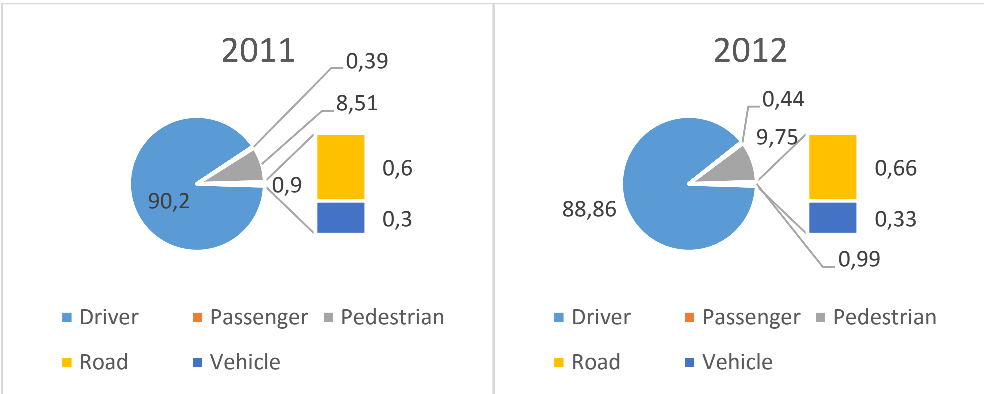


Fig. 4.
Yearly rates of divided road lengths (km)
Source: General Directorate Highways

The driver defects (faults) are accepted to be the most important factor in traffic accidents, followed by pedestrian behaviors, road structure, vehicle quality and passenger faults respectively. Application of traffic laws in Turkey is another effective factor on the high rate of driver faults. Yearly percentages of such defects leading to traffic accidents are given according to years are shown in Figure 5 (Turkish Traffic Law, 1983). Article 52 of NO 2918 Traffic Code is as follows;

Drivers,

a) must reduce their speed when approaching a junction, entering the turn, approaching the hill top, winding progresses on the road, the pedestrian walkway, the level crossings, tunnels, approaching the narrow bridges and culverts, construction and entering to repair areas,
b) must adapt the speed, the vehicle used to load and technical specifications to the road and the conditions required by the weather and traffic conditions.



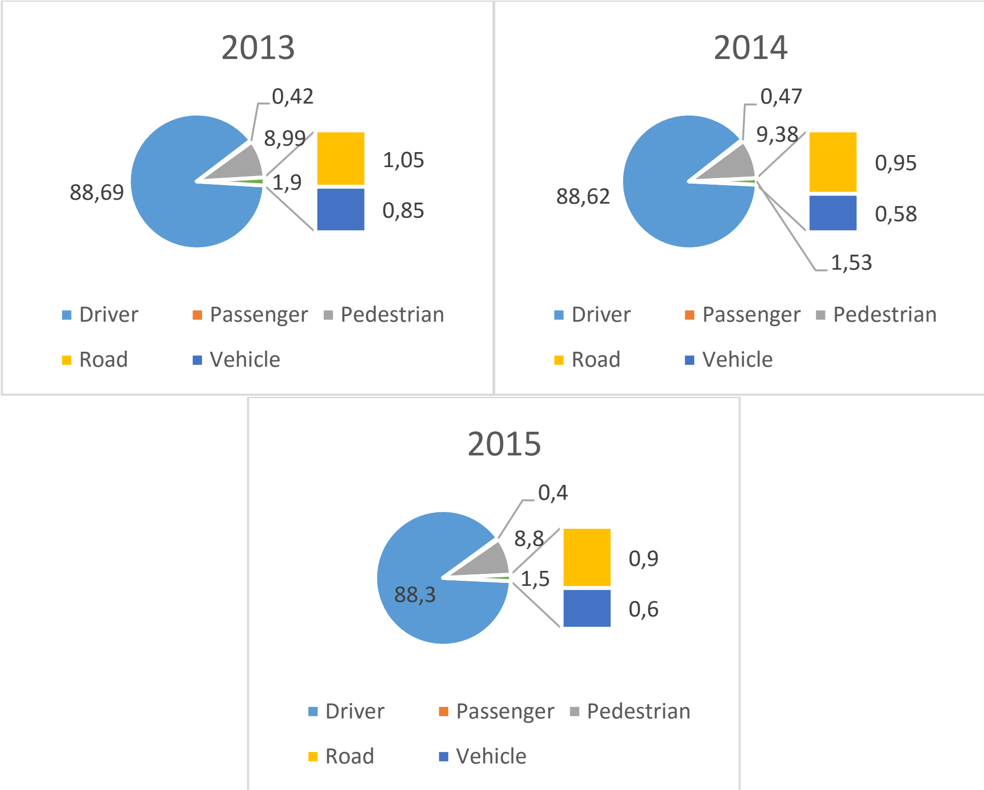


Fig. 5.
Faults causing road traffic accidents
Source: Turkish Statistical Institute

Monthly distribution of traffic accidents is given in Table 2. An increase is seen in the number of traffic accidents in summer months. The reason for this increase may be that in summer, people prefer to go on their holidays using densely highways.

Table 2
Monthly distribution of traffic accidents in 2015

Months	Number of Traffic Accidents	%	People Killed	%	People Injured	%
January	10.443	6,20	221	6,27	17.191	6,03
February	10.057	5,97	195	5,53	16.440	5,77
March	12.352	7,33	243	6,90	20.173	7,08
April	13.309	7,90	248	7,04	21.463	7,53
May	14.365	8,52	309	8,77	24.036	8,43
June	15.603	9,26	302	8,57	26.916	9,44
July	16.872	10,01	440	12,49	30.399	10,66
August	18.249	10,83	428	12,15	32.781	11,50
September	15.855	9,41	337	9,56	26.666	9,35
October	15.380	9,13	342	9,70	26.902	9,44
November	13.155	7,81	222	6,30	21.261	7,46
December	12.872	7,64	237	6,73	20.831	7,31
Total	**168.512**	**100**	**3.524**	**100**	**285.059**	**100**

Source: Turkish National Police

It is seen when the traffic accidents happening in 2015 in Turkey that the majority of traffic accidents were experienced in daytime (Figure 6) due maybe to the transportation needs during the daytime.

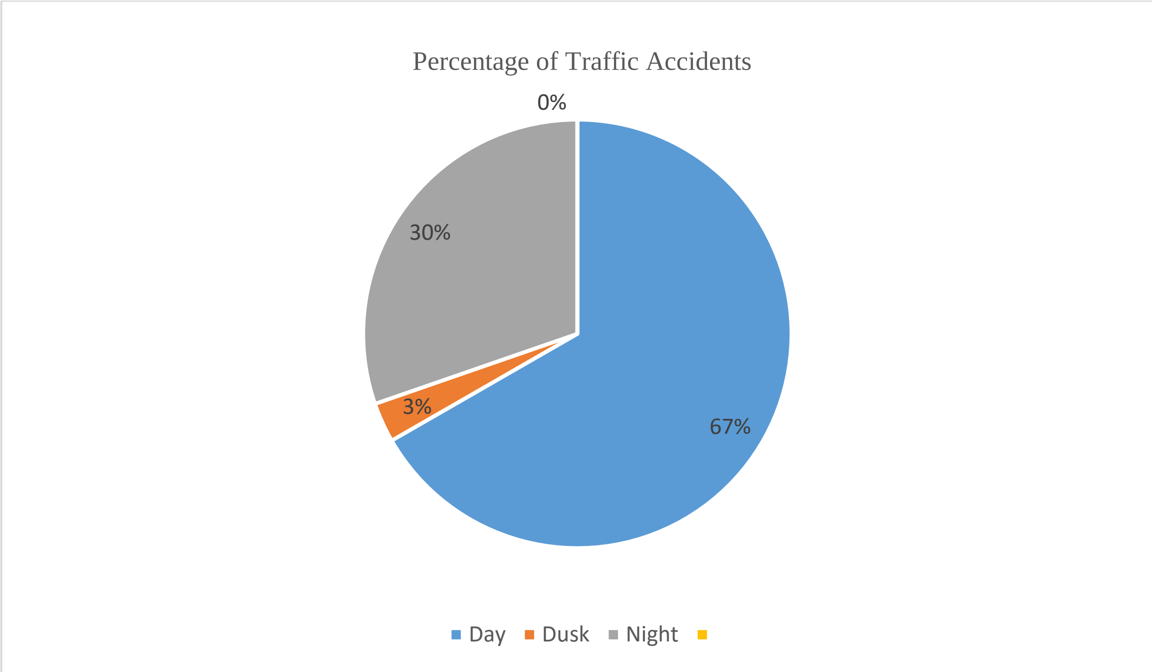


Fig. 6.
Percentage of traffic accidents in daytime
Source: Turkish Statistical Institute

4. Conclusion

Traffic accidents cause death of thousands of people and loss of millions of dollars in Turkey as well as all over the world. Therefore, precautions must be taken to reduce their losses. This study analyses the data related to the traffic accidents happening last year in Turkey by presenting the situation with the help of tables and figures. Traffic accidents are events happening depending on various and numerous factors most important of which may be human, road, transportation and environmental ones. Data of traffic accidents were analyzed by considering the months of the year and time of a day. It can be seen that the highest rate of traffic accident is experienced in August and during daytime. Generally, the number of people killed in traffic accidents is in declining trend. As a result of this situation, it can be suggested to improve human security and the safety of vehicles in traffic and provide better standards of road.
It is possible to reduce traffic accidents by taking effective measures. Suggestions to reduce the rate of traffic accidents and analyze better traffic accidents are described below:

1) Most of the traffic accidents happen as the result of non-compliance with traffic rules. This case reveals the importance of traffic education. Therefore, government agencies and civil society organizations should raise the awareness of people about traffic and rules.
2) Although the seat belt is placed in passive safety systems, it reduces the risk of death and injury to a minimum. The decision was taken to advise on the use of seat belts by governments on 18 October 1983, seat belt was accepted to be a requirement in the scope of the Code put in to force on 16th June 1985.
3) It seems from traffic accident statistics in Turkey that drivers are responsible for the highest rate of defects. The defect from road structure is even under 1% (Figure5). A higher defect rate paths from the road in countries with higher standards than Turkey, this rate is close to 0 in Turkey. It is thought that this result may be caused by the effective application of article 52 of Code 2918.
4) Road transportation ranks the first among passenger and freight transportations in Turkey. In this case, the number of vehicles in traffic causes to be more. The use of other modes of transportation should be expanded. In this way the density of road traffic will slightly be reduced.

References

Abdelwahab, H.T.; Abdel-Aty, M.A. 2001. Development of artificial neural network models to predict driver injury severity in traffic accidents at signalized intersections, *Transportation Research Record*, 1746(1): 6-13.
Andreassen, D.C. 1985. Linking deaths with vehicles and population, *Traffic Engineering and Control*, 26(11): 547-549.
Atalay, A.; Tortum, A. 2010. According to traffic accidents between 1977-2006 years clustering analysis of provinces in turkey, *Pamukkale University, Engineering Science Journal*, 18(13): 221-229.
Atalay, A.; Çodur, M.Y; Gökdağ, M. 2013. Temporal analysis of traffic accidents. In *Proceedings of the 4th Highway Traffic and Safety Symposium*, Ankara.

Atalay, A.; Tortum, A.; Çodur, M.Y. 2013. Modeling of traffic accidents by using geographical weighted regression analysis. In *Proceedings TMMOB Geographical Information Systems*, 11-13 December, Ankara.

Atalay, A.; Çodur, M.Y.; Tortum, A. 2013. The modelling with clustering analysis of the provinces in turkey according to traffic accidents at the year 2011. In *Proceedings of the 26th European Conference on Operational Research*, Rome.

Atalay, A.; Tortum, A.; Çodur, M.Y. 2014. Modelling of traffic accidents by using factor analysis, *International Journal of Traffic and Transportation Safety*, 1(1): 35-54.

Çodur, M.Y. 2012. *Traffic accident prediction models: applications for surrounding highways of Erzurum*, Thesis-Doctor of Philosophy, Atatürk University Science Institute, Erzurum.

Çodur, M.Y.; Tortum, A. 2012. Development of traffic accidents prediction model with neural network. In *Proceedings of the 25th European Conference on Operational Research*. 8-11 July. Vilnius, Lithuania.

Çodur, M.Y.; Tortum, A.; Çodur, K.M. 2013. Erzurum North Ring Road Accident Prediction Model with Generalized Linear Regression, *Iğdır University Journal Institute Science and Technology*, 3(1): 79-84.

Çodur, M.Y.; Atalay, A.; Tortum, A. 2013. Erzurum-Tortum road accident prediction model with generalized linear regression. In *Proceedings of the 4th Highway Traffic and Safety Symposium*, 2013 Ankara.

Çodur, M.Y.; Tortum, A. 2013. Erzurum-Pasinler road traffic accident prediction model, *Ordu University Journal Science Technology*, 3(2): 39-49.

Çodur, M.Y; Atalay, A.; Tortum, A. 2013. Erzurum north ring road accident prediction model with artificial neural network. In *Proceedings of the 26th European Conference on Operational Research*, Rome.

Çodur, M.Y.; Atalay, A.; Tortum, A. 2015. Geographic information systems aid traffic accident analysis: Erzurum-Horasan road case. 11. Transportation Congress, 27-29 May, İstanbul.

Çodur, M.Y.; Tortum, A. 2015. An artificial neural network model for highway accident prediction: a case study of erzurum, Turkey, *Promet – Traffic and Transportation*, 27(3): 217-225.

Durduran, S.; Sarı, F.; Erdi, A.; Cevdet, A. 2011. Web-based analysis of traffic accidents using GIS: example of Konya. In *Proceedings of the TMMOB Congress*. 31 October- 04 November, Antalya, Türkiye.

Karasahin, M.; Terzi, S. 2003. Determination of hazardous locations on Isparta-Antalya-Burdur highways through GIS, *Pamukkale University Journal of Engineering Sciences*, 9(3): 305-311.

Kabakuş, N.; Tortum, A.; Çodur, M.Y. 2012. Traffic accidents occured in districts of Erzurum using with geographical information system, *Ordu University Journal Science Technology*, 2(2): 78-92.

Kim, K.; Nitz, L.; Richardson, J.; Li, L. 1995. Personal and behavioral predictors of automobile crash and injury severity, *Accident Analysis and Prevention*, 27(4): 469-481.

Mason, J.K.; Purdue, B.N. 2000. *The Pathology of Trauma*. 3nd edition. Arnold, Oxford University Press, Oxford, 1-17.

Miaou, S.P.; Harry, L. 1993. Modeling vehicle accidents and highway geometric design relationships, *Accident Analysis and Prevention*, 25(6): 689-709.

Mussone, L.; Ferrari, A.; Oneta, M. 1999. An analysis of urban collisions using an artificial intelligence model, *Accident Analysis and Prevention*, 31: 705-718.

Smeed, R.J. 1949. Some Statistics Aspects of Road Safety Research, *Journal of the Royal Statistical Society, Series A* Part I, 1-34.

Tortum, A.; Kabakuş, N.; Çodur, M.Y.; Atalay, A.; Uluğtekin, N. 2011. Clustering analysis of the districts in Erzurum for traffic accidents between 2002 and 2007, *Scientific Research and Essays*, 6(13): 2850-2857.

Tortum, A.; Çodur, M.Y.; Kılınc, B.; 2012. Modeling Traffic accidents in Turkey using linear regression analysis, *Iğdır University Journal Institute Science and Technology*, 2(3): 69-78

Tortum, A.; Bolakar, H.; Çodur, M.Y.; Kabakuş, N. 2015. The analysis of traffic accidents in Erzurum province and ıts districts through use of geographical ınformation systems, *Journal of Traffic and Logistics Engineering*, 3(2): 2850-2857.

Üstündağ, O.; Duran, C. 2009. Analyzing of the traffic accident among the city roads by the geographic information systems (GIS): Elazıg Example, *E- Journal Of New World Sciences Academy*, 4(1), Article Number: 4A0001, ISSN: 1306-3111.

Wikipedia, 2015. Available from Internet: <https://tr.wikipedia.org/wiki/Kategori:T%C3%BCrkiye_n%C3%BC fusu>.

World Health Organization Report, 2015. Available from Internet: <http://www.who.int/mediacentre/factsheets/fs358/en.htm>.

ROAD SAFETY PERCEPTION: GENDER DIFFERENCES – MONTENEGRO CASE STUDY

Mirjana Grdinić[1], Vladimir Pajković[2]
[1,2] University of Montenegro, Faculty of Mechanical Engineering, Podgorica, Montenegro

Abstract: Differences between male and female drivers in terms of crash rates are evident in a wide range of countries. Usually males were those who significantly being more at risk than females. A surveys show that females are more compliant with traffic regulations and that males are less concerned about road safety issues. In addition, males attach less importance to risky behaviours and consider accidents a less serious problem than do females. This research, conducted among young adult drivers and non-drivers in Montenegro, presents difference in males and females perception of road safety problems and risky behaviors.

Keywords: road safety perception, young adults, male drivers, female drivers, non-drivers.

1. Introduction

Road traffic accidents have become a major public health concern in both developed and developing countries. Driving safety has become a priority issue in developing countries in view of the increasing motorization levels (Akaateba and Amoh-Gyimah, 2013). Driving safety is affected by various factors, which together determine the level of traffic safety or risk. Several studies have suggested that the human factor plays an important role in road accidents. The influence of socio-demographic variables such as gender, age, educational levels and personality variables on driver behaviour has been widely established by several studies in high income countries. The Attitudes report produced in Spain highlights the fact that approximately 90% of the accidents are due to human factors such as unsafe driving, personality traits and attitudes (Gonzales-Iglesias et al., 2012). In addition, greater focus should be on driver attitudes and behaviour towards traffic safety. In most of the counties, including Montenegro, traffic safety campaigns have focused exclusively on the entire population with few or no targeted campaigns at specific groups of drivers. Therefore, identifying the gender and age differences in driver attitudes towards traffic regulations and traffic violations will provide relevant information towards more target-specific and effective road safety campaigns in the country.

2. Gender differences

Females and males have some differences in driving behavior and attitudes that affect their safety and crash experience. Differences between male and female drivers in terms of crash rates are evident, with males being significantly more at risk than females (SIRC, 2014). Male drivers account for about 65% of total passenger vehicle kilometers travelled and women account for only 35% (Ginpil and Attewell, 1994). This reflects both the fact that males are more likely to have a driver’s license and that, on average, male drivers travel more each year. The probability of being injured in traffic accident is 25% higher of man than that of women (Degraeve et al., 2015). On average, male car drivers are about 46% more likely to be involved in a fatal crash per distance travelled (Ginpil and Attewell, 1994). In Sweden, males were involved in 1.9 more injury crashes per 1000 licensed drivers than female drivers during the first year of licensed driving. In France, women have 2.5 times fewer points removed from their driving license, and are convicted 6.2 times less often for offenses (Degraeve et al., 2015).
According to the literature, males in general take more risk on the road, commit more driving violations, they are involved in more motor vehicle crashes than females and they are less concerned about road safety issues. In addition, males attach less importance to risky behaviours and consider accidents a less serious problem than do females (Gonzales-Iglesias et al., 2012). In contrast, female drivers drove less than males and evaluated their driving skill lower. Female drivers were less involved in accidents and they committed less traffic offenses than males. Female drivers showed a more positive attitude toward traffic safety and rules than males. This gender difference is most marked in the population under the age of 24 years, but is also evident among older drivers (SIRC, 2014).

2.1. Crash differences caused by male and female drivers

According to Ginpil and Attewell (1994), many of the differences reflect contrasting travel patterns. For example, female driver crashes are relatively more likely to occur during daytime and on weekdays. Men are more frequently involved in accidents related to traffic rule violation, however, fatal crashes caused by female drivers were much less likely to have involved drink driving or speeding. In 37% of fatal crashes caused by male car drivers, alcohol intoxication of the driver responsible for the crash was considered to be a contributing factor. The corresponding percentage for females was only 16%. Younger male drivers were more likely to be involved in single-vehicle and fatal head-on crashes while female drivers were more likely to involve in left-and right-hand crashes. Younger female drivers were more likely to be involved in fatal rear-end crashes compared to younger male drivers. Amarasingha and Dissanayake (2014) showed that approximately 30.5% of young female drivers had restrictions on their driver licenses at the time of crash. A majority of young drivers involved in crashes held valid driver licenses. About 4.0% of young

[1] Corresponding author: grdinicm@ac.me

female drivers and about 5.7% of young male drivers were not wearing seat belts at the time of the crash. Approximately 5.9% of young male drivers were under the influence of alcohol at the time of the crash. Also, about 24.7% of young-female-driver-involved crashes and 31.8% of young male driver involved crashes occurred in dark conditions. Mentioned survey also showed that holding a valid license, driving during weekends, crash avoidance, attempting to stop or back, involving non-collision overturn crashes, collision with a pedestrian, and involving head-on crashes were variables that were significant in the female model but not in the male model. Travel on unleveled roadways, travel with passengers, travel on concrete surfaces, travel on wet road surfaces, collision with a vehicle, and rear end collision were the variables that were significant in the male model but not in the female model. There were no differences in terms of the number of passengers carried by cars driven by male or female drivers, but women between the ages of 25 and 39 were most likely to have had young children in the car at the time of the crash. It has been suggested that many crashes involving women may be caused by inattention due to passenger distraction, especially with respect to young children. However, passenger distraction was the cause of only 2% of fatal crashes caused by car drivers with at least one passenger and there was no difference in the incidence of this causal factor for male and female car drivers.

Despite of all, women are still considered as being poor drivers. Many stereotypes of women drivers are still effective. Studies have shown that negative beliefs associated with women drivers could lead to an impairment of their driving performances. Analysis of how individuals perceive men and women drivers may be useful for apprehending and understanding the various speculations and discussion in this area (Degraeve et al., 2015). Women are usually perceived as drivers with high accident rates, which appear to be related to their poor vehicle control and the mismatch between the driving activity and the feminine role in society. In contrast, men are perceived as drivers who are skilled while being careless and committing offenses. In study results, this good driving quality goes hand-in-hand with the good match between the driving activity and the masculine role in society (Granie and Papafava, 2011).

3. Male and female perception

In literature, great effort is putting to portray a psychological understanding of driver behaviour and perceived risk, so several studies were conducted in order to address this issue. Opinions, beliefs and behavioral intentions of different groups of users regarding matters of road safety are a source of relevant information, since they reveal characteristics of their attitudes in relation to mobility and safety, their relations with other users, their experiences and their concerns. Many researches recognized differences according to age and gender. The basis for these differences according to gender may be due to neurochemical structure of humans, hormonal process, global socialization practices, and many others. Several studies were conducted in order to address the issue of drivers perceptions. “Road safety – Analytical report” is survey conducted in June 2010 by The Gallup Organization, Hungary, upon the request of Directorate-General Mobility and Transport, (Gallup, 2010). The research projects like this attempt to understand how individual drivers rate the driving within their country. Another alike project, the SARTRE – Social attitudes to Road Traffic Risk in Europe, (SARTRE 4, 2012) includes several of studies of attitudes conducted in European countries since 1993. Those surveys investigate and compare between countries road safety variables, attitudes, behaviors and support for safety countermeasures.

In Montenegro, a study was conducted during 2014–2015 (Pajkovic and Grdinic, 2014) in order to address the issue of drivers and non-drivers road safety perceptions. Survey questions were based initially on the questionnaire derived by Gallup Organization. The first survey approach was face-to-face questionnaires. These forms were handed out randomly in several locations in couple larger towns, Podgorica and Bijelo Polje, such as apartment’s complexes, supermarkets, and train and bus stations. Additionally, an online survey named *Road safety perception in Montenegro*, was constructed and implemented using GoogleDrive software and its URL was sent to students at University of Montenegro and was posted on Facebook asking young drivers/non-drivers who live in Montenegro to participate. There was a function within the GoogleDrive software that prevented participants from repeating the survey several times. Total number of respondents was 327, with 75% males and 25% females, between 18 and 45 years old: 85.63% of those were drivers (79.29% males and 20.71% females). Car drivers and non-drivers responses are presented focusing on differences between genders.

Firstly, frequency that respondents drive a car was investigated. As expected, larger number of those that drive a car most days were man: more than half respondents (55%), in contrast to 25% female. One in ten male respondents said that they did not drive a car; while almost third of female respondents answered they are not drivers, (Fig. 1).

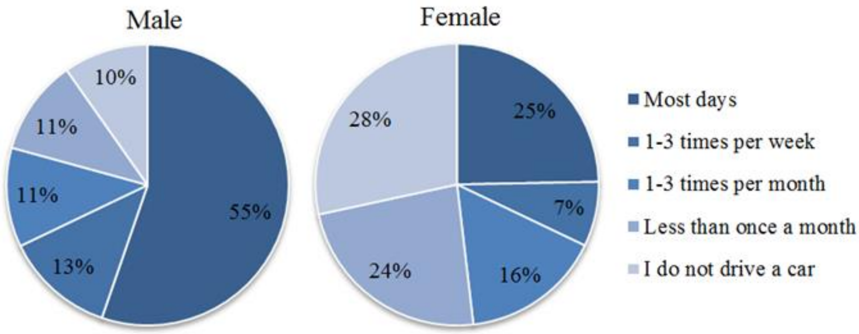


Fig. 1.
Frequency that respondents drive a car

In order to define general attitudes to road safety in matter of gender of respondants, all interviewees were asked to give opinions on if roads in Montenegro are safe, fairly safe, fairly unsafe or unsafe.

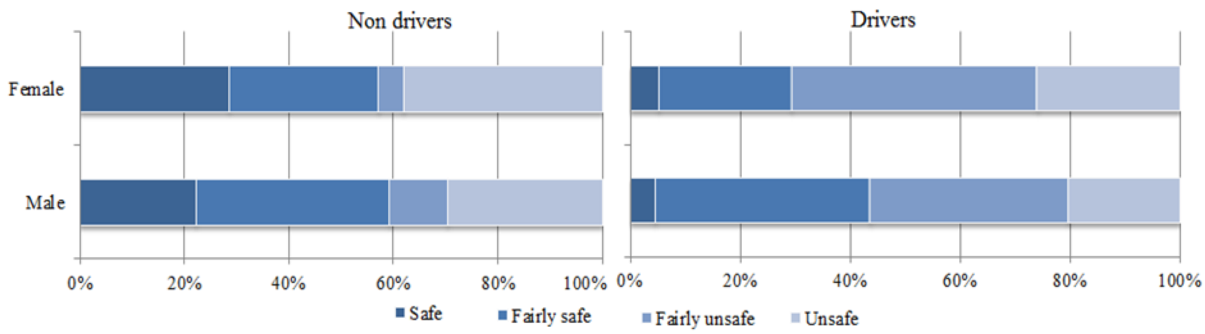


Fig. 2.
General attitudes about road safety in Montenegro

There is a small difference between those respondents who drive and those who aren't. About 25% of non-drivers (male and female) described road safety as safe, while only about 5% of drivers respondents both gender have the same answer. They usually described road safety as fairly unsafe (36% of males and 45% of females) and fairly safe (40% males and 25% females), with small difference between males and females answers. Overall, 60% of male and female non-drivers described the roads as safe or fairly safe, 10% higher than from those who describe as fairly unsafe or unsafe. When drivers are respondents, this proportion has some differences. While 45% of male drivers described road safety as safe and fairly safe and 55% described it as fairly unsafe and unsafe; only 30% of female drivers respondents described it as safe and fairly safe, in contrast to 70% of those who described it as fairly unsafe and unsafe. Based on the calculated average values of the survey respondents, the roads in Montenegro are considered as more or less dangerous, (Fig. 2).
Interviewees were asked about five potential road safety problems: for each one, they were requested to say if it was perceived as a problem and if so, whether it constituted a major or minor safety issue. Both male and female, whether been drivers or not, perceived the issue of people driving under the influence of alcohol to be the major safety problem (about 70% in every category). There is a small difference in answers between drivers and non-drivers that alcohol is a minor problem, where 15% of non-drivers perceive it as minor problem in contrast to almost 25% of drivers (males and females). 5% of female drivers perceive driving after drinking alcohol as not a problem, in addition, about 12% of males (drivers and non-drivers) seeing it as not a road safety problem. Speeding was regarded as the second most important issue. About 60% of all respondents recognized exceeding speed limits as major problem in the country, with small or no differences between males and females answers, or drivers and non-drivers. 25% of female drivers and 35% of female non-drivers perceived speeding as minor problem, while 30% of male drivers and 25 of male non-drivers perceived a same. Average 10% of all said it was not a problem. About 30% of male and female seeing not respecting traffic regulation as major problem, with mentioning only 16% of male non-drivers whose perceived it a same thing. There is a small difference between drivers and non-drivers in answering a question how they perceive when drivers or passengers not wearing seatbelt. About 20% of non-drivers (20% males and 18% females) perceived it as major problem, in contrast with about 15% of drivers (14% males and 16% females). About 75% of non-drivers (73% males and 82% females) perceived mentioned problem as minor problem, in contrast to about 50% (47% males and 57% females) drivers. There are some differences according to males and females attitudes about using mobile phone while driving. Many answers were that this is minor road safety problem, however 23% of male drivers and 12% of female drivers perceived this problem as not a road safety problem. In addition, almost half of female non-drivers (45%) and quarter of female drivers perceived it as not a problem, (Fig. 3).

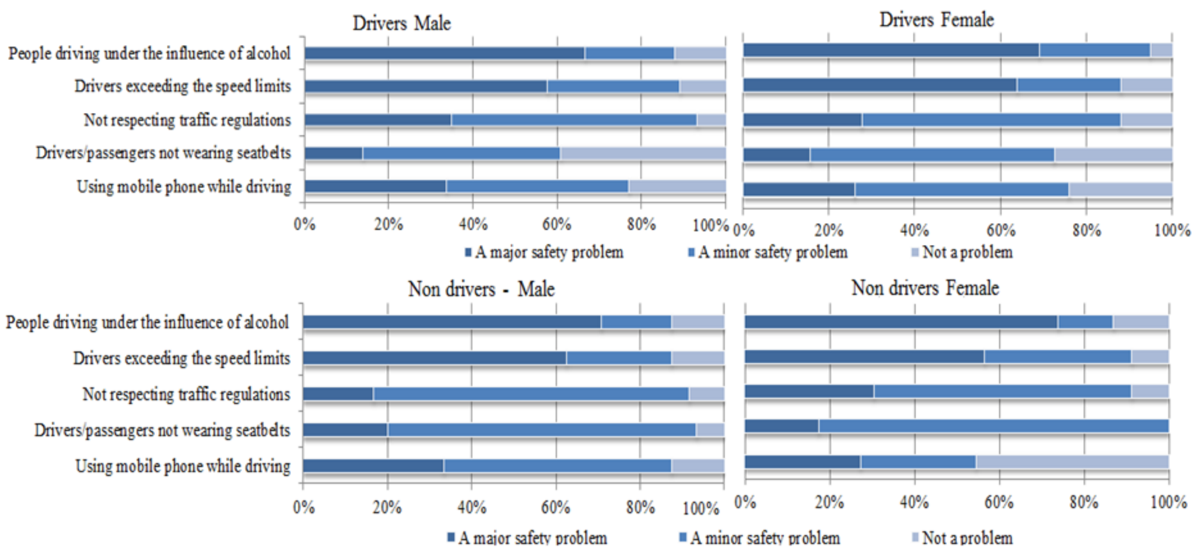


Fig. 3.
Perceptions about the seriousness of road safety problems: non-drivers and drivers

Interwieevers were asked of measures that could help to improve road safety situation. Most of the respondents agreed that first thing that government should do is to improve road infrastructure, which is at very low level, (Fig. 4). There is a slight difference between male and female attitude about increasing traffic monitoring. 17% of females non-drivers would apply this measure, in contrast to 8% of males. With drivers, there is opposite proportion: slightly larger number of males (13%) than females (10%) voted for this measure. Strict penalties are recognized as best measure by non-drivers, 36% of males and 26% of females. However, only about 10% of drivers, both males and females, would approve this measure. Road safety campaigns are last recognized measure by both genders, male and female, while pre-licensing was recognized by female drivers as measure which could help to improve road safety in Montenegro.

In folowing, interwieevers were asked about what government should do about listed measures for younger drivers. Possibilities were to give positive (yes) or negative (no) answer for introducing those measures in domestic law enforcement. Results are graphically presented in Fig. 5. Some differences between male and female answer can be noticed. Analyzing both, drivers and non-drivers, females are stricter according to every measure. Over 80% of female non-drivers approved zero-alcohol measure for young drivers, in contrast with 50% of males. Almost 30% female non-drivers would restrict driving from 23AM to 6PM for this category of drivers. Large gap between male and female attitude is related to limiting speed for young drivers. About 30% of male non-drivers would introduce this measure, in contrast to almost 90% of female non-drivers. Limiting power of vehicle which young drivers use, 30% of female non-drivers find as positive for road safety. In addition, only 10% of male non-drivers would apply this measure. Analyzing drivers answers, there are same conclusions for almost every measures except for limiting power of vehicle. Male drivers were stricter according to it, with above 50% of positive answers, in contrast to 35% of positive female answers. There is no difference between drivers and non-drivers answers, except for mentioned measure for young drivers, limiting power of vehicle, where female non-drivers doesn't see it as large problem and they are mostly against it.

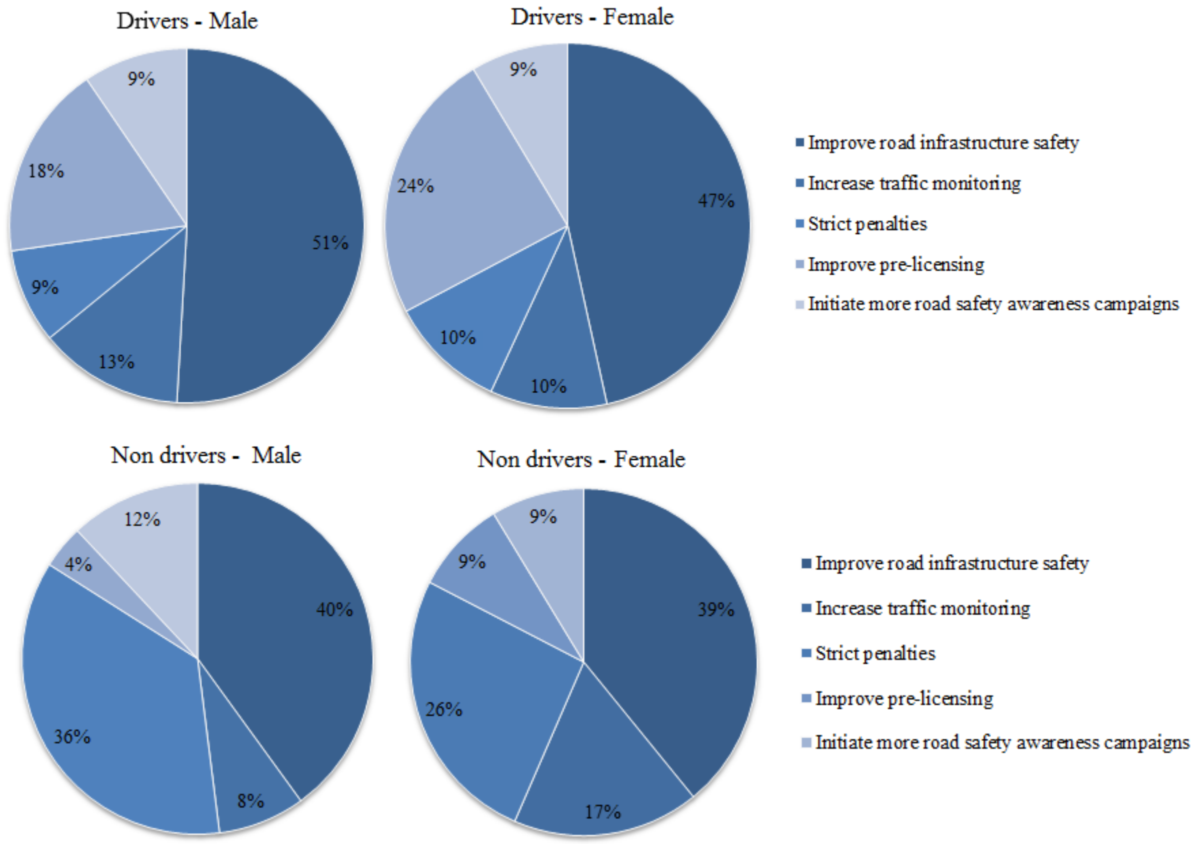


Fig. 4.
Measures to improve road safety

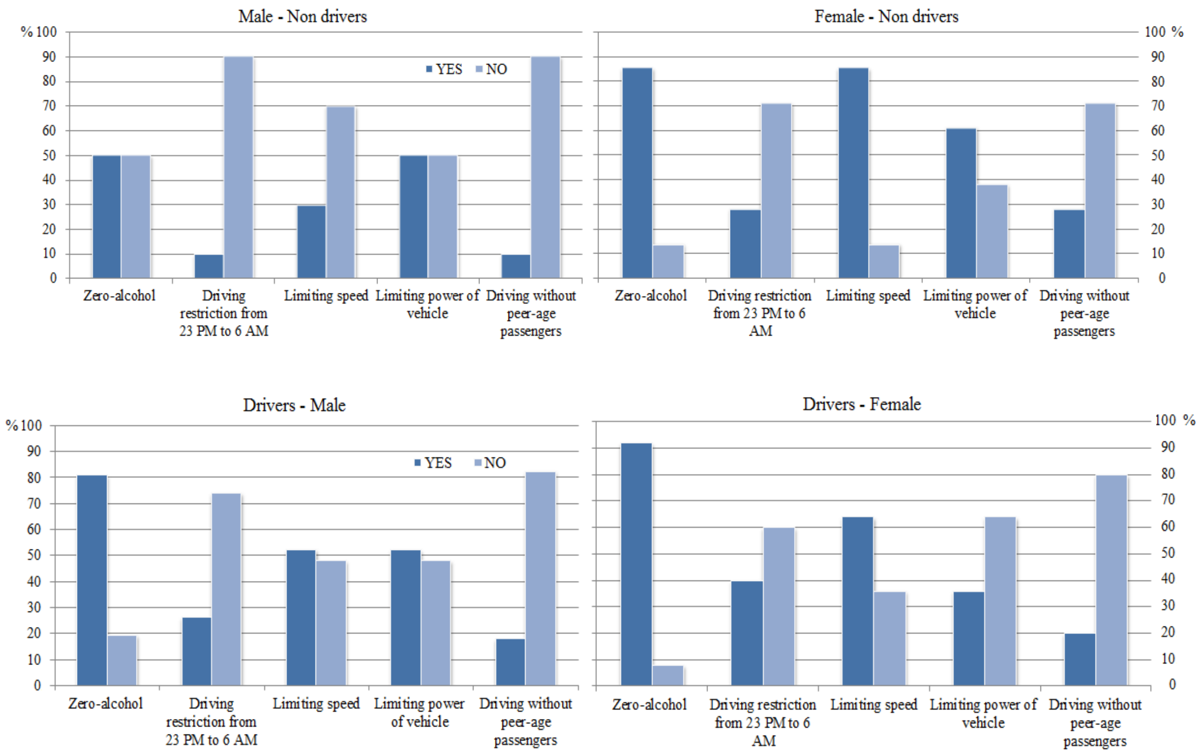


Fig. 5.
Measures for young drivers

4. Conclusion

There appear to be important differences between male and female drivers in terms of travel behaviour, crash characteristics and injury outcome. According to the literature, males in general take more risk on the road, commit more driving violations, receive more traffic citations, and are involved in more motor vehicle crashes than females. Men are perceived as having a higher crash risks than women, whereas women are perceived as having poorer driving skills. This seems to suggest that accidents caused by women are more linked to an inability to adopt the right behavior rather than a lack of caution. Also, there is some differences between male and female opinion of road safety problems. Female, drivers and non-drivers, have stricter opinion according to road safety problem an measures that should be implemented to increase a level of road safety.

References

Akaateba, M-A.; Amoh-Gyimah, R. 2013. Driver attitude towards traffic safety violations and risk taking behaviour in Kumasi: The gender and age dimension, *International Journal for Traffic and Transport Engineering*, 3(4): 479 -494.

Amarasingha, N.; Dissanayake, S. 2014. Gender differences of young drivers on injury severity outcome of highway crashes, *Journal of Safety Research*, 49: 113-120.

Degraeve, B.; Granie, M-A.; Pravossoudovich, K.; Monaco, G-L. 2015. Social representations associated with men and women drivers among French adolescents and adults. Effects of the perceiver's age, sex and the socioeconomic status, *Transportation Research*, 34: 1-17.

Gallup. 2010. *Road safety – Analytical report*, The Gallup Organization. Available from Internet: <http://ec.europa.eu/public_opinion/flash/fl_301_en.pdf >.

Ginpil, S.; Attewell, R. 1994. A Comparison of Fatal Crashes Involving Male and Female Car Drivers. Available from Internet: <https://infrastructure.gov.au/roads/safety/publications/1994/pdf/gender_fat_1.pdf>.

Gonzales-Iglesias, B.; Gomez-Fraguela, J-A.; Luengo-Martin, M-A. 2012. Driving anger and traffic violations: Gender differences, *Transportation Research*, 15: 404-412.

Granie, M-A.; Papafava, E. 2011. Gender stereotypes associated with vehicle driving among French preadolescents and adolescents, *Transportation Research*, 14: 341-353.

Pajkovic, V.; Grdinic, M. 2014. Road safety – perfomance and perception, Montenegro case study. In *Proceedings of the Second International Conference on Traffic and Transport Engineering ICTTE, Belgrade, Serbia*: 375-383.

SARTRE 4. 2012. *European road users' risk perception and mobility*. Available from Internet: <ec.europa.eu/transport/road_safety/pdf/projects/sartre_4.pdf>.

SIRC. 2014. *Sex differences in driving and insurance risk: An analysis of the social and psychological differences between men and women that are relevant to their driving behaviour*. Available from Internet: <http://www.sirc.org/publik/driving.pdf>.

HARMONIZATION OF PROCEDURES OF ROAD SAFETY INSPECTION IN ITALY AND POLAND

Salvatore Cafiso[1], Mariusz Kiec[2], Giuseppina Pappalardo[3], Fabrizia Trovato[4]
[1,3,4] Department of Civil Engineering and Architecture, Via S. Sofia 64, Catania 95123, Italy
[2] Cracow University of Tecnology, Warszawska 24, 31-155 Cracow, Poland

Abstract: Even if, the European Directive 2008/96/CE gives great emphasis to road Safety Inspections (SIs) as an effective tool for safety management of existing roads, relevant issues remain in the use of SIs as source of information to prioritize measures and treatment sections with the highest safety benefit-cost ratio. In the framework of the IASP research program co-financed by the European Commission in the 2007, an inspection procedure aimed at improving the effectiveness and the reliability of the methodology has been defined and a Risk Index (RI) is calculated as a surrogate measure of safety. After the first implementation in the IASP project, further developments were carried out to improve the quality and efficiency of the safety inspections of road network by using low cost equipment (GPS, Tablet, Camera) and specific software tools to support the inspectors' task. The paper shows how the procedure, developed according to the Italian practice, was adapted to comply with the checklists and evaluation criteria of the Polish guidelines. Methods for conducting Road Safety Inspections (SIs) in Italy and Poland are described and compared. The different hazard categories of the two procedures were harmonized to an equivalent risk score taking into account also the regional crash type distribution. Finally, experimental application on about 100 km of road network in both countries shows the applicability of the procedure and gave the opportunity for a comparison of frequency and severity of safety issues in Italian and Polish two lane rural roads.

Keywords: road safety inspection, low cost equipment, Polish guidelines, two lane rural roads.

1. Introduction

The European Directive 2008/96/CE requires the member states to establish and implement procedures oriented on improvement of the existing network, namely: road safety impact assessments (i.e. evaluation of the projects of new investments regarding efficiency of road safety improvements), road safety audits (evaluation of road designs regarding traffic safety), the management of road network safety, and Road Safety Inspections (SIs; the management and security of existing roads in order to identify the road safety related features and prevent accidents). In the aforementioned Directive, great emphasis is given to road SIs as an effective tool for the safety management of existing roads stating: "Once road sections with a high accident concentration have been treated and remedial measures have been taken, safety inspections as a preventive measure should assume a more important role. Regular inspections are an essential tool for preventing possible dangers for all road users, including vulnerable users". Within the Article 6 of the "Safety Inspections" it is also recognized that member states shall carry out safety inspections on existing roads in order to identify the features related to road safety and to prevent collisions and accidents. The use of SIs is one of the measures to improve traffic safety in Europe associated with the assessment of the accident risk on the existing elements of road infrastructure. SIs can be a source of information needed to prioritize treatments in road sections which produce the highest accident reduction and/or the highest safety' benefit-cost ratio. The inspections should be performed periodically and by a competent entity. Member states are also encouraged to apply this directive on other national roads, which are not part of the Trans – European Road Network (TEN).
The aims of the study presented in the paper are the comparison and harmonization of Italian and Polish SIs procedures, the implementation of the Italian experience in conducting the SIs in Poland, and improving the efficiency of the periodic inspections using low cost equipment. Poland has already implemented road safety audit and road safety impact assessments and it is in the way of implementation of the SIs on national roads. Unfortunately, guidelines for carrying out road safety inspections (Budzyński et al., 2013), implemented in Poland by GDDKiA in 2014, do not allow quantification of the accident risk basing on the conducted SIs. Such a possibility is introduced in a method developed in Italy and described in "Identification of Hazard Locations and Ranking of Measures to Improve Safety on Local Rural Roads" (IASP) (Cafiso et al., 2008), in conjunction with Risk Index (RI) (Cafiso et al., 2007) used to predict frequency and severity of accidents when using SIs.
In order to describe problems this paper is divided into 3 main sections presenting:

- IASP procedure for road safety inspection;
- Harmonization of the Italian and Polish guidelines;
- Comparison of frequency and severity of safety issues in Italian and Polish two lane rural roads.

2. IASP Procedure for road safety inspection

The IASP project (Cafiso et al., 2008) was funded by European Commission (DG TREN) and Province of Catania (Italy) with the scientific coordination of the University of Catania. As part of the project, safety inspections procedures, which address rural two-lane highways, have been defined. Albeit many safety inspection procedures already exist, the IASP procedures present some innovative elements and, above all, they are very operational in nature.

[2] Corresponding author: mkiec@pk.edu.pl

IASP procedure is one of the twenty-one models or approaches to road safety management reviewed and assessed by TRL in a recent Project Report PPR770 (TRL, 2015). After comparison, it was selected as one of the six most promising models that should be tested in UK, with iRAP Star Rating, NetRisk, SURE, iRAP Risk Mapping, North Yorkshire Route Assessment Tool. The six models were chosen based on the scores they obtained from the review process and also the impression of how cost-effective they might be given the lack of good evaluation.
The IASP safety inspection can interest in one day about 50 km of road. At least three operators are needed: the driver, the inspector in front seat and the inspector in back seat. Recommended equipment are GPS receiver, digital video camera and checklists. The road is running in both directions at very low speed (about 30 km/h). Checklists are aimed at ensuring that important safety problems are not overlooked. Checklists are a prompt and not a substitute for knowledge and experience, that is, checklists should aid using safety engineering experience and judgment.
IASP checklists are very synthetic (Cafiso et al. 2008), since they relate only to the main safety features which usually are present along two lane rural roads. Moreover, only features which are easily detectable during inspections have been inserted. Features which concern horizontal and vertical alignment (geometric alignment, design consistency, etc.) are not considered since in the IASP safety analysis alignment evaluation is performed as a separate quantitative procedure.
Checklists must be filled in both directions. Front seat and back seat inspectors, which have different views of the road, compile different checklists filling the boxes with a step of 200 m (24 s at 30 km/h). In order to simplify the inspectors' task, any checklist is split in two parts: part A has to be compiled on site, part B can be compiled both on site and during the video examination performed in the office.
In order to get an easy and low cost solution to simplify the inspectors' work, it was decided to build an Android application. By means of an easy-to-use interface the application allows the user to insert inspection data for each section of the road using own tablet. To improve accuracy in vehicle positioning, an external GPS receiver can be connected with Android application running on the tablet. Finally, to associate also images of the road space, frames recorded by a video-camera installed on the vehicle can be geo-referenced and linked to the inspection data through a system of synchronization based on the GPS UTC time used as a metronome for all devices. The architecture and organization of the system is shown in Figure 1. More information about this system are available in Cafiso et al., 2014.

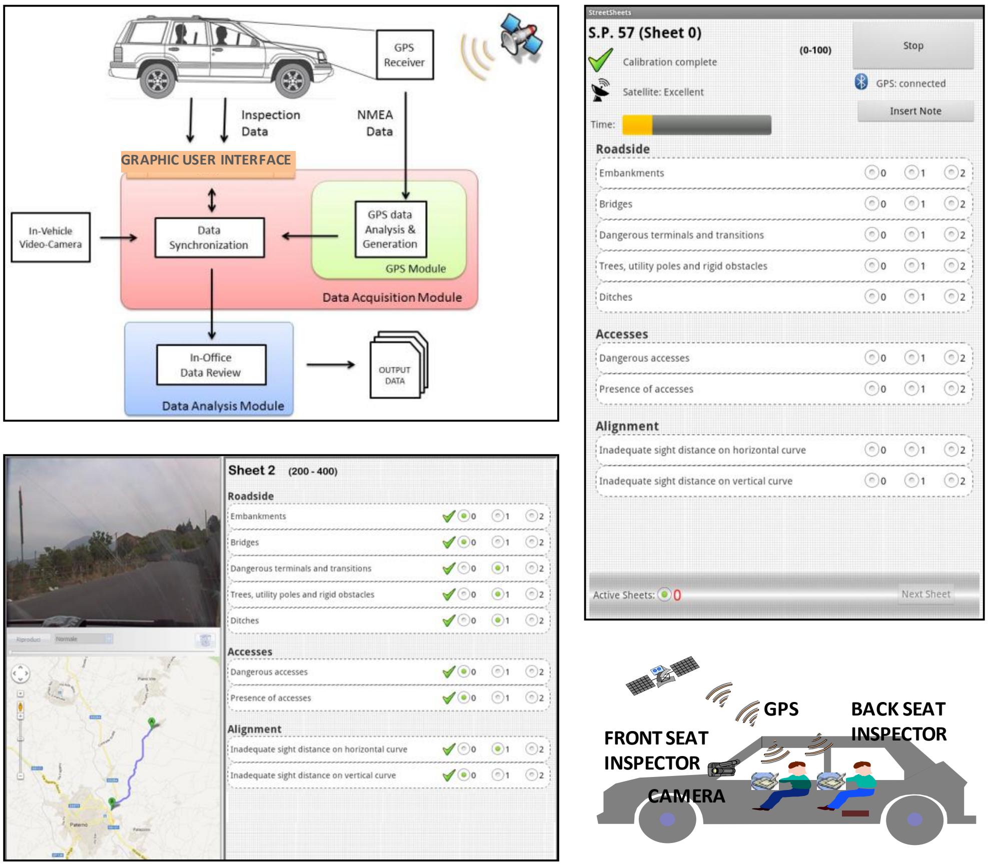


Fig. 1.
Architecture and organization of the system

In the IASP procedure, safety issues are ranked as:
- high score problem (rank 2),
- low score problem (rank 1),
- no problem (rank 0).

Ranking of safety issues can be used both as an aid for the prioritization of the safety measures and as an aid to road agencies in measuring the effectiveness over time of their safety improvement programs. After the preliminary

inspection, in the office, the team analyzes videos and (if wasn't done on site) complete part B of the checklists. Checklists are compiled in both directions referring in particular to the right side. By brainstorming among the team member checklist results are examined and the final version of the checklists is edited.
The IASP manual (Cafiso et al., 2008) suggests for each problem the recommendation typologies. Recommendations are engineering solutions to the reported problems. They indicate the type of measures, without specifying detailed technical issues. Problems and recommendations are disaggregated in order to highlight the safety issues of each road feature, but road safety improvement requires an integrated approach where interaction among different measures must be taken into account, as well. As final result of the meeting, a preliminary report describing general problems and recommendations is edited. Moreover, some sites requiring further specific inspection (site visits) might be identified.

3. Harmonization of the Italian and Polish guidelines

As defined in the Polish guidelines (Budzyński et al., 2013), the road safety inspections are carried out using three type of controls, General inspection, Detail inspection and Special inspection during the night and in road works.
General inspection applies to the national road network, are regulars and periodic and are performed during daylight hours inspecting the elements located along the road (roadway and roadside) and assessing their impact on road safety in order to allow an efficient and effective action of maintenance and planning of investment work consistent with the existing system of road maintenance in Poland. Detailed inspections consists in a specific control of sections or points where there is a concentration of accidents identified during the risk classification, or the results of the general inspections, during which you have identified a very high average risks of serious accidents (fatalities and serious injuries). Specials inspections by night and in road works are the analysis of the perception of road in the absence of natural light to verify that the road works are carried out properly organized and protected from the point of view of road safety, including the organization of the traffic in the work area and protection for all road users. Polish guidelines gives specific checklists for carrying out these controls, in which issues found along the road are grouped in characteristics of the road, elements of surrounding roads, marking, road safety and characteristics of traffic. These checklists are available for all Polish roads, without the creation of specific checklist for some class.
Polish checklists are formed by a high number of issues, that do not allow an easy filling out of sheets during the continuous analysis. Safety inspections are usually carried out manually without support of electronical devices.
This study focuses only on the checklists for General inspection than can be filled by two inspectors running the road with a vehicle instrumented with simple and low cost equipment (GPS, video camera, tablets). To this aim two separated checklists are taken into account: one for the front seat inspector and one for the rear seat inspector, with respectively 33 and 27 issues.
For this reason, the goal of the comparison between Polish guidelines and IASP procedures, has been to find a common checklist, synthetic and complete, that it could be adopted both in Poland and in Italy. Through a taxonomic approach, it has been observed that a lot of fields in the Polish checklist could be joined in existent Italian fields, while issues, that hadn't any correspondence, have been added in a new common checklist. The fields related problems at intersections are grouped in separate checklists, while issues that aren't present in two lane rural roads, have been excluded.
It is possible to see that there are some many correspondences with Italian issues, that have allowed us to create, based to the Italian module, a new checklist that can be compiled, during a continuous analysis, in a sufficient amount of time for sections of 200 m of length at a speed of 30 km/h. This new checklists, reduced in comparison to the original Polish checklist, for front seat inspector and for back seat inspector are shown in Figure 2.

(a)

	0.2	*0.4*	*0.6*	*0.8*	*1.0*
PART A					
Roadside					
I1 - Embankments (P22, P23, P44,P45)					
I2 - Bridges (P44, P45)					
I3 - Dangerous terminals and transitions (P46)					
I4 - Trees, utility poles and rigid obstacles (P59, P27)					
I5 - Ditches					
Alignment					
I6 - Inadequate sight distance on horizontal curve (P2, P16, P26, P28, P34, P60)					
I7 - Inadequate sight distance on vertical curve (P2, P16, P26, P28, P34, P60)					
I8a - Geometric design consistency for horizontal curves (P1)					
I8b - Geometric design consistency for horizontal tangent (P1)					
I9 - Geometric design consistency for vertical alignment (P1)					
PART B					
Accesses					
I10 - Dangerous access (P54)					
I11 - Presence of access (P55)					
Vegetation					
I12 - Bad condition of vegetation (P35)					
I13 - Vegetation close to the edge of roadway (P36)					

(b)

	0,2	*0,4*	*0,6*	*0,8*	*1,0*
PART A					
Cross section					
I14 - Lane width (P9)					
I15 - Shoulder width (P17, P18, P19)					
Pavement					
I16 - Friction					
I17 - Unevenness (P24, P27)					
I18 - Dirtiness (P25)					
Road drainage					
I19 - Lack of runoff water sites (P20)					
I20 - Incorrect design (P21)					
Delineation					
I21 - Chevrons (P64)					
I22 - Guideposts and barrier reflectors (P64)					
PART B					
Signs					
I23 - Warning signs, regulation signs (P37, P38, P39, P40, P47, P48, P49, P63)					
Markings					
I24 - Edge lines (P42, P43, P63)					
I25 - Center lines (P42, P43, P63)					
Bike paths					
I26 - Incorrect geometrical parameters (P14)					
I27 Lack of bike paths (P15)					

Fig. 2.
Checklist ITA_PL for General Inspection (a): for Front Seat Inspector; (b) for Back Seat Inspector (I: Italian item; P:Polish item)

In Poland, each issues identified during the inspection should be initially classified as defects to be removed immediately and defects that are candidate for long term interventions. The defects should be evaluated and qualified within four risk categories:

- Class A – small,
- Class B – medium,
- Class C – large,
- Class D – very large.

Class D defects should be corrected as soon as possible. Pending the correction or repairs may need temporary protection. Defects in this class can cause serious consequences of road accidents, hence the need for a rapid intervention. Defects of Class B and C should be removed as part of maintenance and modernization in function of priority depending on the degree of irregularity, traffic volume and characteristics of the place. Defects of Class A are malfunctions to remove as part of the regular maintenance. In the checklist fields it is possible to give a score for each issues 0, 1, 2 in function of the severity of the problem found along the road (0: no problem, 1: medium score, 2: high score problem), complying with the rules explained in the IASP manual [6].
In a previous work (Cafiso et al. 2014) it was proposed a harmonization between Italy and Poland of the score in terms of equivalent safety risk (Figure 3). The interested reader may refer to Cafiso et al. (2014) for a more detailed discussion on the harmonization procedure.

		Polish risk category																	
Safety issue		Embankments	Bridges	Dangerous terminals and transitions	Trees, utility poles and rigid obstacles	Ditches	Inadequate sight distance on horizontal curve	Inadequate sight distance on vertical curve	Dangerous accesses	Presence of accesses	Lane width	Shoulder width	Friction	Unevenness	Chevron	Guideposts and barrier reflectors	Edge lanes	Center lines	Warning signs, regulation signs
IASP severity score	***0***	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1	B	B	A	A	A	A	A	C	C	A	A	A	A	A	A	A	A	A
	2	C	D	B	B	A	B	B	D	D	B	B	A	A	A	A	A	A	B

Fig. 3.
Comparison of IASP severity score and Polish risk categories

4. Case study: RSI in Italy and Poland with IASP procedure

In Italy, the inspections were conducted on 18 sections of the two lane rural roads along a length of 207 km while in Poland, the inspections were conducted on 7 sections of the regional roads in Malopolska with a length of 184 km, of which 98 km were rural sections and therefore were included in the study. Other sections, passing through built-up areas, with a length of 86 km were not included in the study.
To compare the two national samples, the frequency distribution of safety issues is reported for each severity score in Italy and Poland. In the following details about the score classification and results of comparison are reported.
Figure 4 shows the results regarding embankments and terminal and transitions. For example, an embankment section is classified at high problem if at least one of the following conditions is present:
more than 5 m unshielded or shielded with ineffective barriers, or more than 3 m and steep slopes unshielded or shielded with ineffective barriers, or more than 3 m and steep slopes shielded by low containment safety barriers.
The situation in which it is advisable to report a high score problem with dangerous terminal and transitions are roadside and bridge barriers with no breakaway terminals, terminals buried in the ground, roadside barriers not connected, roadside and bridge barriers connected without transitions. In Poland the frequency of highest risk score “2” for these issues is much higher than Italy (17.9% and 20,3% respectively higher in Poland).

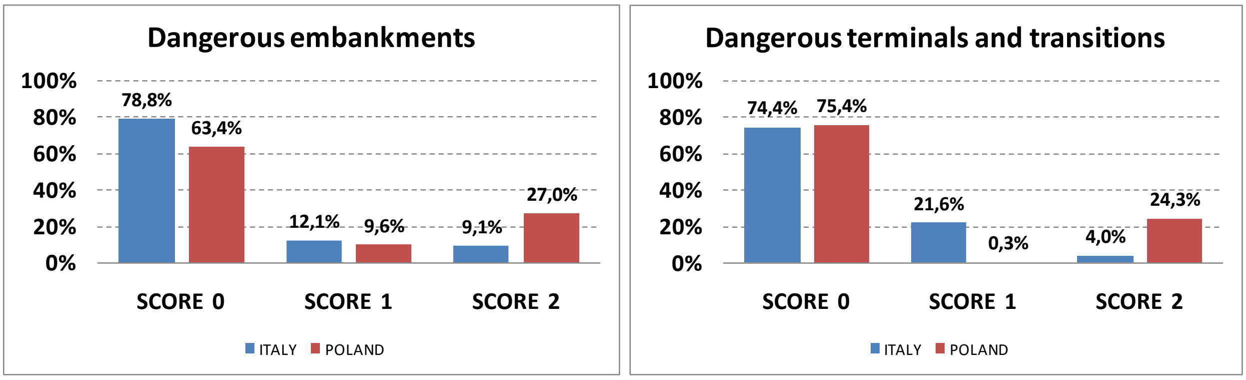


Fig. 4.
Frequency distribution for embankments and terminal and transitions scores in Italy and Poland

Fig. 5.
Poland: dangerous embankments

The situation in which it is advisable to report a high level problem with trees, poles and other obstacles are:

- high diameter trees/poles and concrete utility poles less than 3 m from the roadway;
- rows of trees;
- rigid obstacles with exposed front face or corner less than 3 m from the roadway.

Again, in Poland percentage of trees, utility poles and rigid obstacles with a high score problem (score 2) is higher (+24%) than in Italy (Figure 6).

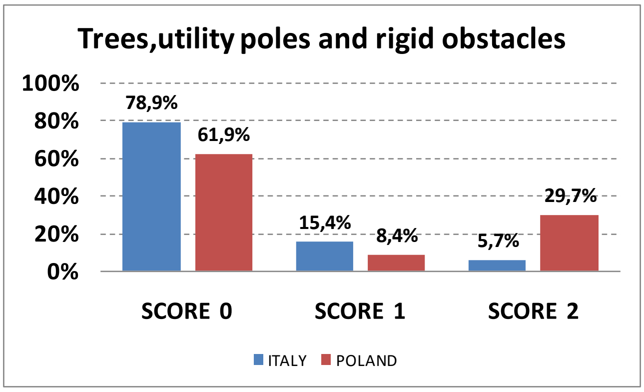


Fig. 6.
Frequency distribution for trees, utility poles and rigid obstacles scores in Italy and Poland

Fig. 7.
Poland: rows of trees

An access is classified at high score problem if located on horizontal curves, on crest curves, on site with poor visibility, close to less than 30 m from the intersections. Low score problems are narrow, not signalized with road markings or delineators, unpaved driveways. In Poland percentage of dangerous access with a high (score 2) and low (score 1) problem are higher than in Italy (Figure 8).

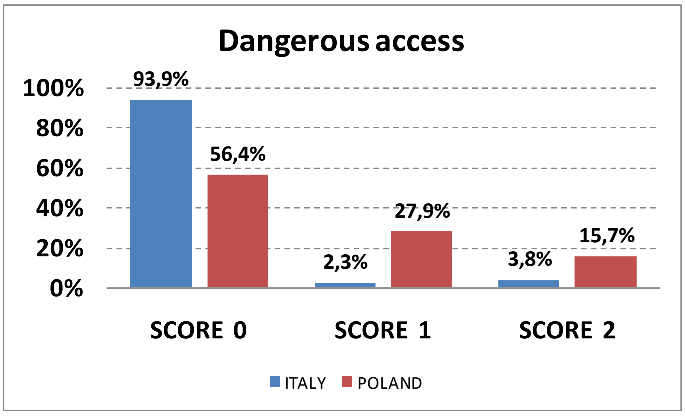


Fig. 8.
Frequency distribution for dangerous access scores in Italy and Poland

Fig. 9.
Poland: unpaved access

A high score problem of inadequate sight distance is:

- for on horizontal curves, less than 50 m due to the presence of obstacles along the whole inside of the curve;
- for vertical curves, less than 50 m due to the presence of a crest.

For these issues (Figure 10), in Poland the percentages are higher than Italy (+14,7% for horizontal and +8,1% for vertical sight distance).

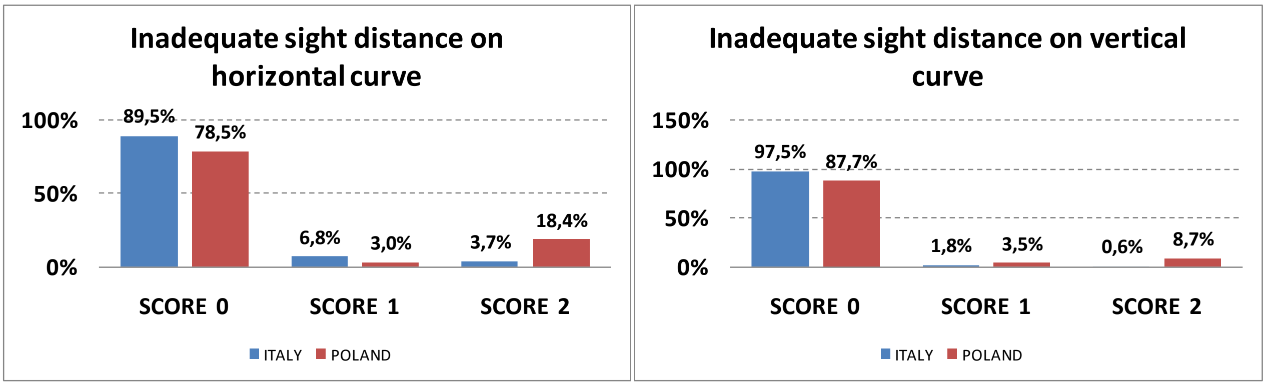


Fig. 10.
Frequency distribution for inadequate sight distance on horizontal and vertical curve scores in Italy and Poland

Fig. 11.
Poland: inadequate sight distance on horizontal curve

For edge lines, the situations in which it is advisable to report a high score problem are missing or very faded edge lines; for centre line, these situations are missing or very faced centre lines and discontinuous line with no overtaking sight distance. Unlike the other cases, in Italy the percentages for high score problem are higher than Poland (+47.4% for edge lines and +62.4% for centre lines more in Italy) (Figure 12).

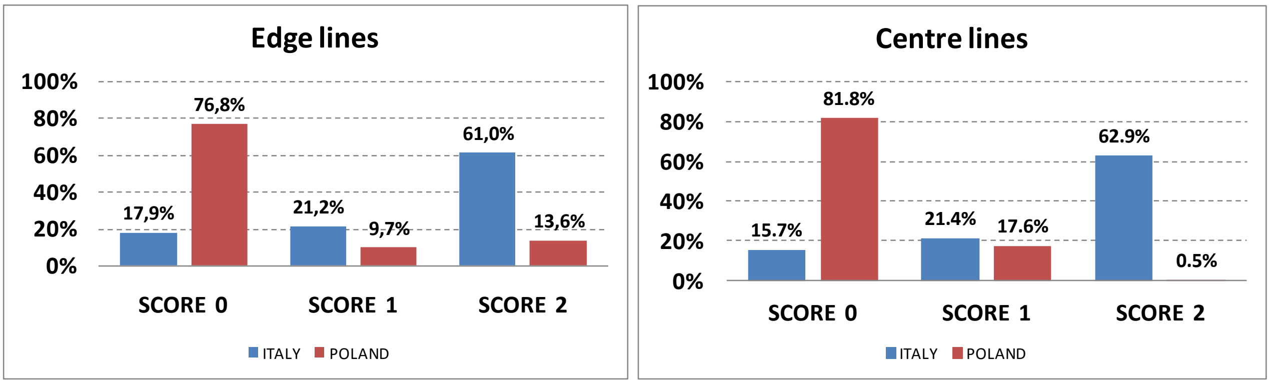


Fig. 12.
Frequency distribution for edge and centre lines scores in Italy and Poland

Finally, for cross section, the checklist for road safety inspections considers lane width and shoulder width, as well. A lane width of less than 2,75 m has to be classified as a high score problem, as well as a lane width more than 4,50 m. There is a low problem if the width is between 2,75 m and 3,25 m.
A shoulder width of less than 0,30 m is considered as a high score problem, while a width of between 0,30 m and 1,00 m is a low score problem. In Poland, the percentage of lane width at low score is higher than Italy (67,5%) while there is a higher percentage of shoulder width is high score (98,1%) (Figure 13).

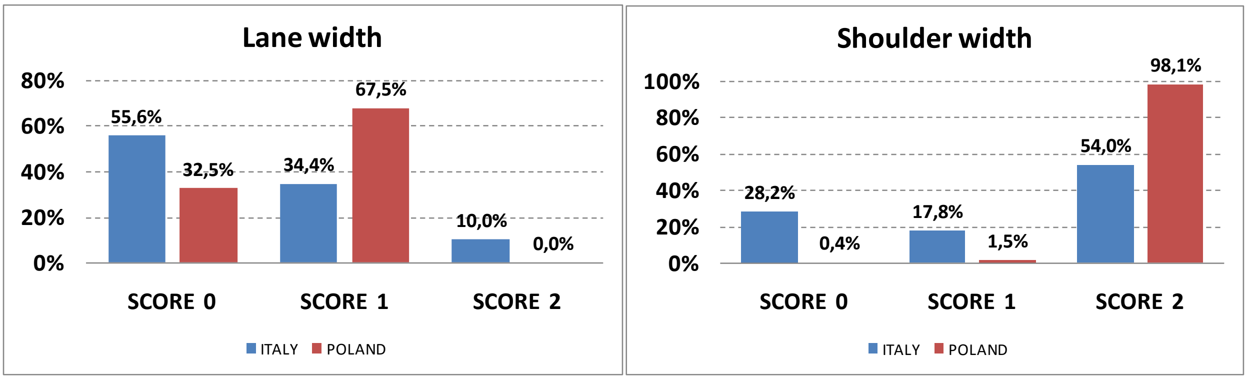


Fig. 13.
Frequency distribution for lane and shoulder width scores in Italy and Poland

Fig. 14.
Poland: inadequate shoulder width

The Chi-Square test of independence was further used to check the statistical significance of the differences in the proportions between the two samples. Results reported in table 1 figure out that all the previous differences between the proportion of score 2 safety issues, are significant, as well.

Table 1
Chi-Square test for comparison of Italian and Polish safety issues at score 2

	ITALY			POLAND				
	sample	sum of sample	%	sample	sum of sample	%	$\chi 2$	P-value
Embankments								
SCORE 2	94	1035	9.1%	129	476	**27.0%**	81.90	0.00
Terminal								
SCORE 2	41	1035	4.0%	116	476	**24.3%**	142.58	0.00
Trees								
SCORE 2	60	1035	5.7%	142	476	**29.7%**	160.47	0.00
Dangerous access								
SCORE 2	40	1035	3.8%	75	476	**15.7%**	63.78	0.00
Inadequate sight distance on horizontal curve								
SCORE 2	39	1035	3.7%	88	476	**18.4%**	89.80	0.00
Inadequate sight distance on vertical curve								
SCORE 2	7	1035	0.6%	42	476	**8.7%**	66.78	0.00
Edge lines								
SCORE 2	631	1035	**61.0%**	65	476	13.6%	293.17	0.00
Center line								
SCORE 2	651	1035	**62.9%**	3	476	0.5%	513.57	0.00
Line width								
SCORE 2	103	1035	**10.0%**	0	476	0.0%	49.28	0.00
Shoulder width								
SCORE 2	559	1035	54.0%	467	476	**98.1%**	288.91	0.00

5. Conclusion

Based on the conducted comparison and analysis of the results of the road safety inspection performed on regional roads in Poland and Italy it can be concluded that:

- The results (in Italy and Poland) are promising for the international transferability of the IASP Safety Inspections procedures and tools.
- It is possible to apply the IASP method and equipment to carry out Safety Inspections in Poland, which would comply with the Polish guidelines.
- To ensure efficiency of the Safety Inspections, it is necessary to limit the number of issues and classes of risk in Polish checklist, which should be identified during the inspection. To this aim, checklist developed in the present paper could be considered.
- The proposed procedure and tools can improve effectiveness of the Safety Inspections process and its usability in Poland and Italy, as well.
- From the point of view of road network features and management, limiting the discussion to the two samples of roads in Italy and Poland, results pointed out as the lack of maintenance for marking and sign are more relevant on Italian roads, Polish rural roads are more effected by structural deficiencies related to roadside protection, alignment and cross section.

References

Budzyński, M.; Gaca, S.; Jamroz, K.; Michalski, L. 2013. *Instrukcja kontroli stanu bezpieczeństwa ruchu drogowego*. Politechnika Gdańska.

Cafiso, S.; Di Graziano, A.; Giudice, O.; Pappalardo, G. 2014. Tools for Road Inspection and Safety Management. In *3rd International Conference on Transportation Infrastructure*, Pisa, April 22-25, 2014.

Cafiso, S.; Kiec, M.; Milazzo, M.; Pappalardo, G.; Trovato, F. 2014. Application of safety inspections for evaluation of two – lane regional roads in Poland, *Archives of Civil Engineering*, LX(4): 453-473.

Cafiso, S.; La Cava, G.; Montella, A. 2007. Safety Index for Evaluation of Two Rural Highways, *Transportation Research Record: Journal of the Transportation Research Board*, 2019: 136-145.

Cafiso, S.; La Cava, G.; Montella, A.; Pappalardo, G. 2008. *Manuale per le Ispezioni di Sicurezza delle Strade Extraurbane Secondarie e Locali – Operative Procedure for Safety Inspections on Two – Lane Rural Roads* Project TREN – 03 – ST – S07.31286 – Aracne Editrice. ISBN 978-88-548-1429-5. Gennaio 2008.

Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management. Available from Internet: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0096:EN:NOT>.

Fletcher, J.; Mitchell, B.; Bedingfeld, J.; Silverman, K.K. 2015. *Road Safety Model*, Project Report PPR770, Transport Research Laboratory.

SESSION 12: ROADS: PLANNING, DESIGN AND CONSTRUCTION ISSUES

RURAL ARTERIAL ROAD PLANNING AND DESIGN STEPS

Müge Özgenel[1]
[1] *Department of Highway Project Design - BOTEK Bosphorus Technical Consulting Corp., Turkey*

Abstract: This paper highlights road design stages for low volume roads in Turkey. Starting from tendering procedures (e.g. General Directorate of Highways) brief explanations regarding planning, design with supporting information of transportation design criteria. In Section 1, tendering and proposal preparation stage is explained. Following this section; in section 2 design of the alignment and important considerations given in detail. In Section 3, roles and usage of surveying, catchment basin, geological and geotechnical issues are explained. In Section 4, design of intersections / interchange and engineering structures along with their link to the alignment are explained. Landscaping, drainage and traffic project design briefly explained in Section 5. And finally in Section 6, project delivery documents are given and explanations are made just before work completion is made.

Keywords: low volume road, Turkey, General Directorate of Highways.

1. Tendering and proposal preparation

In this article starting from Rural Arterial Road Project tendering stage, preliminary design, final project stages of Malkara-Hayrabolu-Alpullu-D100 State Road in Turkey is explained. Malkara-Hayrabolu-Alpullu-D100 State Road is approximately 72 kilometer in length, starting from Malkara on Tekirdağ-Çanakkale D110 State Road, passing near Hayrabolu and Alpullu and connecting to Lüleburgaz-Babaeski D100 State Road.

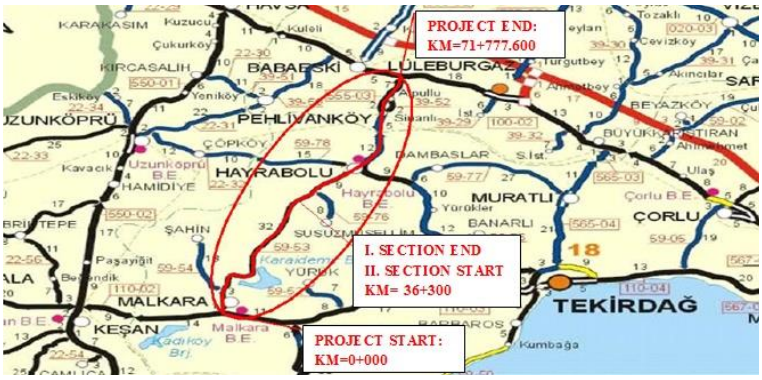


Fig. 1.
Project area

1.1. Tendering

Projects announced by General Directorate of Highways (GDH), starts with a call for tender and publishing the required documents and interested companies apply to purchase tender documents.

1.2. Expression of interest

Initially at the first stage, an expression of interest phase take place for the companies who are willing to participate and win the project. In this Expression of Interest Stage following information are required for the company wishing to participate:

- Company information, Trade Registry Gazette, ISO Certificate, Company Turnover, Letter of Application, Relevant Experiences, Offered Staff List and CV's.

Purpose of the EOI stage is to identify the companies willing to enter the tendering stage and control if the company satisfies the conditions of the GDH and have the capability to carry out project activities.
Required documents in a dossier is delievered to the Client, before or on the date and the hour stated in the tender notice.
As EOI stage finalizes and results come out, companies are invited for the proposal stage.

[1] Corresponding author: muge.ozgenel@botek.info

1.3. Tender preparation

Companies invited for the tender submit their Technical and Financial Offers on seperate envolopes and finally wrapped all together in a single package based on; Administrative Specifications, Technical Specifications, Plan and Unit Price Tables (If the Tender is according to Unit Price) or Lump Sum Rate Letter of Tender.

For Malkara-Hayrabolu-Alpullu-D100 Road the Financial Offer is on Lump Sum Rate.

Technical Offer consists of:

- General information of the region (population, climate, seismicity, cultural, touristic aspects)
- 1/25000 scaled plan and profiles and explanations
- Field visit report
- Geological report along the alignment
- Proposed staff list, CV's, diplommas, social insurance contribution indications
- Related references and work completion certificate.

Financial Offer consists of:

- If the proposal is according to Unit Price; every service is given in unit price, additionally a financial proposal letter is also presented.
- If the proposal is according to Lump Sum; a Lump Sum Rate Letter of Tender is submitted.

Proposal is delivered to the Client, before or on the date and hour stated in the tender notice.

In the evaluation stage, initally Technical and afterwords Financial Proposal Envolopes is opened. The company which gets the highest score from overall Technical and Financial Proposal entitled to win the tender, inorder to accept the project and sign the contract meet with the Client on the date and hour stated to the company with a letter after the announcement of the results.

The winner company start the studies with the guidance of the Specifications given by the GDH to the Selected Companies to carry out the project in appropriate standards.

The standards found within the project cd which was presented to the interested companies at the tendering stage are:

- Highways Final and Preliminary Design Engineering Services Technical Specification
- Investigation Engineering Services Technical Specification
- Highway Flexible Pavement Design Manuel
- Highway Tunnel As Built Project (Final Design) Technical Specification
- Technical Specification Consisting of Detail and Feature Catalogue, National Data Exchange Format, Map Particular Signs and Classes, Point, Facility, Plan, Chart, Canvas, Sheet and Sheet Classification Examples
- Highway Geodetic and Photogrammetric Map Engineering Service Works Technical Specification
- Large Scale Map and Map Information Production Regulations
- Environmental Effect Evaluation- Consultancy Services Technical Specification for Project Introduction Report Preparation
- Bridge Project-Traffic Marking-Road Lighting-Landscape Project Specifications

2. Design of the road geometry

Designing a particular road consists of two main stages; Preliminary Design and Final Design.

In Preliminary Design Stage, the winner company decides with the opinions of the Client whether to go along with the alignment and profile (1/25000 scaled) proposed in the tendering stage. During the investigation of the corridor, on 1/25000 scaled maps, Road Design Engineers determine the most suitable alternative in terms of technical and economic aspects, and transfer information to Google Earth to obtain KMZ files and get up-to-date information about the region. Residential areas, archeological sites, touristic facilities, industrial and military facilities, cemeteries, power transfer lines, natural gas pipe lines, current and planned infrastructure facilities are considered.

After the requirements of the Client understood well enough, the designer presents an alignment. The Consultants Design Team design the Alignment in coordination with the current terrain and road profile is drawn accordingly. The design should consider geographic conditions and be in accordance with the geometric standards. (Highway Design Manual, April, 2005)

Following the completion of the alignment and profile design, appropriate cross section selection is made for the special regions and along the road alignment.

For intersecting roads and roads connecting residential areas, the accessibility is provided by areas possible and suitable for intersection design after detailed consultations with GDH experts and key experts within the company.

The data required for Road Design is given by GDH, including Road Data Table.

Summary information extracted from Road Data Table for Malkara-Hayrabolu-Alpullu-D100 State Road which is given by GDH is as follows:

Table 1
Road data table

Horizontal Alignment Design	R > 600 m for 2x1, 2x2 Road with V=100 km/h	R > 380 m for 2x1, 2x2 Road with V=80 km/h
Vertical Alignment Design	**Sag Vertical Curve;** Max 500 m,	**Crest Vertical Curve;** Max 600 m
Maximum Longitudinal Slope	%4 - %6 2x1 and 2x2 Roads with V = 110 km/h, 90 km/h	
Maximum Superelevation	%4, %6, %7, %8	
Lane Width	3,5 m	
Central Median Width	4 m	
Shoulder Width	Inner; 1 m	Outer; 2.5 m.
Total Platform Width	27,5 m	

The standards are important for level of service, comfort, drainage, aesthetic, car headlamp visibility range etc.
Road Design Engineers work on alternative alignment at the initial stage of the project. Alternative Alignments are studied on 1/5000 scaled base maps. The widths of the maps are determined accurately by the Client, covering 1-4 km width strip area. Possible alignment or alternative options for slope plan and profiles are shown in the same project sheet in 1/5000 scale.
Considering the approved Location Plan, Project Alignment is determined consisting of 1/1000 scaled Horizontal and 1/100 – 1/1000 scaled vertical alignment at the Final Project Stage.
When presenting the studied and designed project to GDH following information is deem important.
Critical sections, large scale engineering structures and special locations requiring geological precautions, intersection type connection points and side road lines are drawn into same project sheets or on separate plan-profile sheets. Detail project sheet of intersection is given separately.
In order to make earthwork calculations and detect the locations of the structures for the designed and approved alignment plan and profile, cross sections in critical regions with 100 meter intervals are taken from the numerical model in Autocad Civil 3D Environment (1/200 – 1/400 scaled)
Preliminary Project Report is also a part of the design and presented with the project. Additional to the project report Preliminary Project BOQ is also submitted.
After the approval of the Preliminary Project Design, Engineers prepare Final project.
At this stage following Projects and Reports are prepared.
Project Geometric Elements and Report Preparation

a) Horizontal Alignment
b) Vertical Alignment
c) Superelevation, Cross Section and Detail Project Sheets
d) Side Roads and Connection Roads
e) Alternative and Relocation

Drawing Project Volumetric Elements and Calculations

a) Drawing Clearance Height and Cross Section Sheets
b) Cubage Calculations
c) Bruckner Calculations
d) Preparation of Bill of Quantities (BOQ)

Project Sheets and BOQ Report Preparation

a) Head and Type Sheets, Plan Profile Sheets
b) Engineering Structures and Road Work BOQ

Current linear Structures Displacement and Service Facilities is also designed by Road Design Engineers at this stage.
At last Final Project Report is presented to Client for examination and approval.

3. Surveying, catchment basin, geology, geotechnical issues and pavement

3.1. Surveying

Surveying takes place after an alignment has been agreed with the Client. Approximate required mapping area stated before at the tables given in Financial Proposal forms by the Client. Winner Company provides detailed mapping data for the alignment and start working on the alignment and profile.
Required surveying area stated in the Technical Specification during tendering stage. To give an example, In Highway Final and Preliminary Design Engineering Services Technical Specification 1 kilometer corridor (corridor width is 200 m) 20 Hectare is required to be obtained by the Consultant.
1/25000 scaled maps are used at both tendering stage and preliminary corridor study stage. After careful considerations engineers pass through the next step and start working on 1/1000 scaled maps.

Following this, after site investigations and detailed observations made by experienced engineers and consultation with GDH experts, the limits and borders of the required survey area frames are defined.
The required measurements of surveying for the alignment is made and transferred to computer as numerical data in Autocad Civil 3D Environment to form the surface area for our project alignment as a map base.
Surface area is the first step to obtain detailed information about alignment geometry and to analyze road alignment and road profile in detail.

3.2. Catchment basin

Catchment Basin is an important piece of the Road Design puzzle. Drainage is a must for Road Design as to prevent road from distortion during and after 20 years maintenance time.
At the initial stage of the project, flows and catchment basin are drawn on 1/100.000 or 1/ 25.000 scaled maps in order to make an analysis of the existing conditions. Areas of the catchment basin and locations of the required culvert and river bridges is determined by Environmental Engineers. At the end of this stage with a calculation report, road alignment hydrological analysis is presented.
For Final Projects, Hydraulic and Hydrologic Studies is performed according to approved Preliminary Studies.

3.3. Geology

In tendering stage, geology experts conduct a site visit for the mentioned alignment and make investigations accordingly to acquire Geological Conditions of the region. Report including important landmarks and special conditions is written on site visit report for further studies.
After detailed investigation of the current Geological Condition, slope gradient are determined by Geology Engineers.
Required geological preventions are determined by Geology Engineers according to conditions.
All together with site investigations, laboratory results and studies performed inclination of the slopes is obtained.
Cut Slope ratio and bench requirement is determined according to Soil Investigation Report, in cuts located on soil ground, cut slope used is 2:1 and on high cut areas Bench design is constituted.
For Fill Slopes the following inclinations will be used after geological and geotechnical investigations.

- $0 < h < 1.50$ m; 4:1 (4 horizontal: 1 vertical),
- 1.50 m $< h < 2.00$ m; 3:1 (3 horizontal: 1 vertical),
- 2.00 m $< h < 5.00$ m; 2:1 (2 horizontal: 1 vertical),
- $h > 5.00$ m; slope inclination is determined according to material used to make fill slopes,
- $h > 8.00$ m; for this condition, stability analysis for fill slopes are made.

Before geological and geotechnical investigations finalization, 2:1 slope inclinations are used both in fill and cut slopes.
With the approved Preliminary Project, Geological and Geotechnical Studies is prepared for the Final Project.

3.4. Geotechnical

Geotechnical Engineers analyzes the conditions and as a result determine appropriate solutions; eg. Walls,
Seismicity and Natural Risk Analysis, Bearing Capacity Calculations, Settlement Calculations, Stability Analysis for critical fill sections and required precautions are presented in Geotechnical Report.
At Final Project stage, Projects of Sheet Wall, Retaining Wall and prevention structures on sea, riverside and streambed is designed by Geotechnical Engineers.

3.5. Pavement

In addition to the design of the road geometry, Pavement Engineer determines the pavement structure.
In this case, flexible pavement is used for our project. Flexible Pavement is designed by Pavement Engineer considering; CBR, Mr values of the samples taken from the soil along the alignment, Traffic Composition and Traffic Volume, Rainfall, Climatic Conditions of the Region etc.
For our project and in general pavement structure consists of the following layers:

- Wearing Course (5 cm)
- Binder Course (6 cm)
- Bituminous Base Course (8 cm)
- Plant Mix Base Course (15 cm)
- Broken Stone Subgrade (15 cm)

Pavement Thickness selected from the table in Highway Flexible Pavement Design Manual according to Traffic Categories.

4. Intersection / interchange design and engineering structures

4.1. Intersection / Interchange design

Main purpose of an intersection design is to provide continuous flow for main and side roads, to increase safety, control speed, reduce delay due to deceleration and stopping actions, to provide adequate level of service.
An intersection is designed as at grade junction or grade seperated junction; considering conditions of the terrain, traffic volume and safety.
Mandatory conditions for an intersection design are; Safety, Adequate Level of Service, Economy and Aestehetic Issues.
In an intersection design, the designer requires the following data and made design accordingly:

Regional Data:

- Topographical conditions, maps and dimensional drawing of the intersection region
- Vertical and horizontal geometry, cross sections, pavement conditions of the intersecting roads.
- Conditions bringing limitations on cultural, historical, physical, legal topics within the intersection effect region
- Current soil and drainage system
- Local, zoning roads, current or planned intersection category and types within the intersection region
- Current zoning road and expropriation borders
- Demand of the related local authority and institutions
- Location of special facilities and authorities

Interchange Signalization Projects are presented to the Client at the Final Design Stage.

Traffic Data:

- Traffic survey of main and side roads (according to vehicle class and hour, day, average annual daily traffic)
- Peak hour values
- Vehicle characteristics and class
- Vehicle speed for all intersecting roads.
- Passenger count and movement; expecially on urban transitions
- Accident reports, analysis and statistics
- Capacity analysis of the current intersections / interchanges
- Capacity analysis of the planned intersections / interchanges

Considering all the listed data, by determining intersections /interchanges and connection roads, Slope Plan and Profiles are prepared.
Intersection projects are submitted to GDH with an offical writing, and comment received afterwards from the experts.
After the receipt of the comments from GDH, Road Desing Engineers immediately make revisions, finalize and submit to GDH.
At final design stage, an intersection report and final project of the choosen intersection alternative is submitted to the Client.

4.2. Engineering structures

Road Design Engineers determine the location and scale of small and large scaled engineering structures; bridges, tunnels, and viaducts.
Revisions of the engineering structures are made after presenting the proposed engineering structures and receipt of comments from GDH.
After acceptance take place, Road Design Engineers transfer information to Structural Design Engineers to analyze the structures in detail, make calculations, prepare project sheets and calculation reports.
Additionally, location and dimensions of overpasses and underpasses, including pedestrian passes are determined by Road Design Engineers in consultation with Structural Design Engineers.
After the location has been finalized Structural Design Engineers prepare Detail Design Sheets.
For Final Design:

a) Small Scale Engineering Structures (Transmission Structures)
b) Large Scale Engineering Structures (Bridges, Viaducts)
c) Tunnels

are presented to the views of the Client and for approval stage.

5. Landscape, drainage and traffic

5.1. Landscape

At the preliminary stage of landscape project, considering road area data requirement, programme is created. Planning and project area work recommendations, environment interaction values, economic and other aspects (technical), comparisons are made accordingly and following this landscape project sheets are prepared.
In addition to the project sheets submitted, a report is presented. Landscape Project Report covers the following topics; topography, geology, drainage, soil properties, climate, regional characteristics, water existence, fauna, vegetation, historical and cultural values.
With the approved Preliminary Landscape Project and Report, depending on planning and size of the project area, Final Projects are drawn on 1/1000 scaled Project Sheets.
These Final Landscape Projects are used as a base for As-Built-Projects.
In general, purpose of Landscape in Road Design, is to prevent headlamp light to reach drivers eye coming from the opposite direction, in terms of aesthetic means, to provide prevention from noise and dust and to be in harmony with the present environment that our road alignment passes through.
The project that are presented on Final Project stage are; Landscape and Irrigation Projects.

5.2. Drainage

Catchment Basin Studies highlights the path for drainage as pre-studies for culvert design is made during this stage. In general Road Drainage branches into two parts;

- Surface Drainage Structures
  Drainage Trench, Culverts, Kerb, Vertical Drains, Collectors
- Subsurface Drainage Structures
  Stabilization Ditch, Horizontal Drains, Vertical Sand Drains, Stone Drains, Drainage Gallery (Culvert) are done according to Geotechnical Investigation Report.

Environmental Design Engineer further study on Culverts, Drainage Trench, Kerb, Vertical Drains, Collectors and present a Hydraulic Report consisting of these structures along with their calculations. For Final Design stage, revisions of the approved Preliminary Projects and Drainage Projects are prepared.

5.3. Traffic sign and safety project

Traffic Sign and Safety Project sheets include; traffic control elements, horizontal, vertical, traffic signal and control region signs.
The projects are designed to provide traffic safety and studies are made accordingly.
Main Sources to be used in Project Sheet Preparation are:

1. Highway Traffic Law and Specifications published
2. Traffic Signs Manual I, II
3. Highway Technical Specification
4. Highway Traffic Safety Control Manuel
5. Highway Design Manual
6. Client Certified Guardrail Publication
7. Signalized Traffic Sign Technical Specification
8. Related Publications, Standards and Specifications of GDH
9. Related Turkish Standard Institute Standards (TS 498, TS 500 etc.)

Considering above Specifications, 1/1000 scaled Traffic Project Sheets are prepared.
Traffic control elements (horizontal, vertical and traffic signal etc.) are shown more significant with respect to road structure and other information on the project.
Project Sheet Details can be found in Traffic Sign and Safety Project Specification.
Guardrail List and Sign List are presented along with foundation and steel construction static calculations, other required calculations within the context of Traffic Sign and Safety Project and presented in A4 format hardcover.
Documents to be submitted for this section are given in detail on Traffic Sign and Safety Project Specifications.
At the Final Project stage, Traffic Safety and Marking Projects are prepared by Road Design Engineers.

6. Project delivery and conclusion

Final Project is delivered to GDH in format and details stated in the Technical Specifications.
Documents submitted to the Client are;

- Project horizontal alignment and 1/1000 scaled map on which intersections / interchanges marked and same with the slope plan within the project
- Project vertical alignment
- Coordinate table of project horizontal alignment (in ITRF96 system and conversion parameter is stated)

- Original drawings of the dimensional drawings
- Cross section drawings (in digital environment)
- Project design sheets (including intersections / interchanges) printed onto the polyester (in the project design sheet bags)
- 2 copy of the complete project in original size and blueprint copy (hardcover or hold and boxed)
- Small sized album (A3 sized); 3 copies
- Original bruckner roll and carriage table
- Assembly, bill of quantities and drawings obtained from other institutions
- Cubage table
- Bill of quantities detail file
- Road work engineering structure quantities table
- Road work quantities table (3 copies)
- CD including grade and coordinate list of slope stake
- Plan and profiles of the displacements
- Satellite file of the alignment
- Scanned copies of the approved design sheets and project report
- Project CD including; digital map, surface information, each document given within the Project.
  2 Copies to the General Directorate, 2 Copies to the Regional Directorate.

Project Design Sheets will be in A1 format polyester and other documents in A4 format. All documents is presented in Turkish unless indicated otherwise by the Client.
In conclusion, after the delivery of the Project and reports with an official letter addressed to GDH, acceptance is presented by the Client and the Work Completion Certificate will be received.

References

AASHTO. 2011. *A Policy on Geometric Design of Highways and Streets.* American Association of State Highway and Transportation Officials. USA. 7-1, 7-2, 7-4 p.
GDH. 2005. *Highway Design Manuel*. General Directorate of Highways, Turkey.
GDH. *Technical Specifications.* General Directorate of Highways, Turkey.
Güngör, G.A.; Sağlık, A. 2008. *Highway Flexible Pavement Design Manual*. Department of Technical Research Pavement Branch Office, Ankara, Turkey.

ESTIMATION OF START-UP LOST TIME AND AMBER TIME UTILIZATION FOR SIGNAL TIMING

Stamenka Stanković[1], Nikola Čelar[2], Jelena Kajalić[3]
[1,2,3] University of Belgrade - Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11000 Belgrade, Serbia

Abstract: The main purpose of urban traffic management is an effective allocation of capacity, by using traffic signals. Lane capacity at signalized intersections is determined by saturation flow value and effective green time. Effective green time duration depends on actual green time, start-up lost time and amber time utilization. Therefore, the accurate determination of effective green is important for intersection performance estimation. The main objective of this paper is to analyze the influence of traffic signal parameters and traffic flow conditions on the value of the start-up lost time and amber time utilization. The research was conducted on more than 300 lanes at 40 main intersections in Belgrade. These intersections operate close to their capacity and therefore an accurate effective green time determination is crucial for system operation. Results have shown that average values of start-up lost time is about 2 s, while amber time utilization vary from 0.3 to 2.5 s depending on different parameters. Considering the number of intersections in the research, it is possible to draw a general conclusion to be used in estimating the traffic signal performance at the same intersection types.

Keywords: signalized intersection, capacity, start-up lost time, amber time utilization.

1. Introduction

Urban networks have a constant lack of capacity, due to disproportion between traffic demands and actual capacity. The problem is most evident at intersections that represent the bottlenecks of the system. Capacity distribution at network nodes is usually preformed by traffic signals. The primary objective of signal timing optimization is to provide the maximum use of intersection capacity, with acceptable level of service. Lane capacity is defined as a maximum number of vehicles that can be served at intersection during one hour. It depends on the queue discharge process during green phase, saturation flow value and effective green time. The capacity of a given lane group may be stated as shown (Webster and Cobbe, 1966):

$$K = \frac{g_e \cdot S}{C} \tag{1}$$

Where: K: lane capacity (veh/h), g_e: effective green time (s), S: saturation flow (veh/h), C: cycle length (s).

Saturation flow is the most important parameter for signal timing optimization. Its value can be determined on the field or estimated using analytical models. Saturation flow models differ in base values, number of adjustment factors and level of their influence. As adjustment factors are used: lane type, adjustment for turn movements, pedestrians, parking maneuvers, heavy vehicles, area type, etc. (Akçelik, 1981; HCM 2010; Webster and Cobbe, 1966).

If the saturation flow value for a specific traffic lane at intersection is considered constant, the capacity value depends exclusively on the effective green time. The effective green time is defined as part of green time during which the vehicles are passing the intersection, and saturation flow has a constant maximum value.

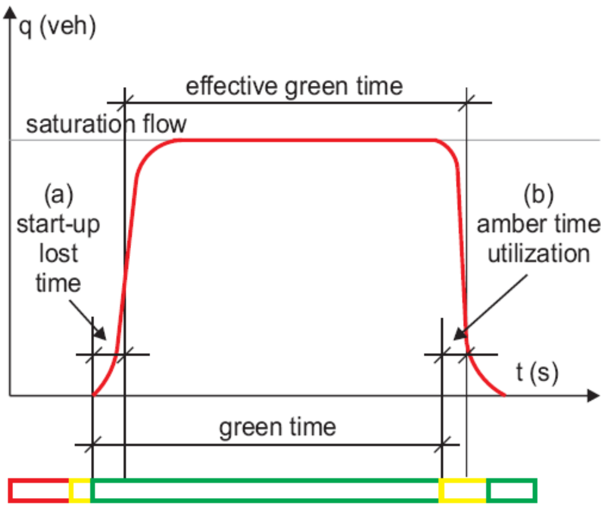


Fig. 1.
Effective green time
Source: Webster and Cobbe, 1966

[1] Corresponding author: s.stankovic@sf.bg.ac.rs

The effective green time is translationally shifted on the time scale relatively to the green time. Mathematically, it differentiates form the green time by the value of start-up lost time and amber time utilization (HCM 2010):

$$g_e = G - a + b \, (\mathrm{s}) \tag{2}$$

Where: g_e: effective green time, G: green time, a: start-up lost time, b: amber time utilization .

Effective green time, as a result of driver's reaction to signal change, depends on several factors: driver’s forcefulness, vehicle characteristics, trip purpose, individual vehicle delay, visibility of traffic signals, intersection geometry, prevailing conditions at intersection and its environment etc.

In theory, the length of effective green time can be shorter, equal or longer than the green time. In signal timing optimization is often assumed that these two variables are numerically equal.

Queue discharge process in a single cycle can be performed in unsaturated and saturated conditions. However, considering a larger number of cycles, queue discharge can be realized in a series of unsaturated cycles, series of saturated cycles or in their combination. Basic assumption of this paper is that the value of effective green time varies depending on traffic flow conditions. Therefore, traffic flow conditions can influence driver’s behavior to a better use of green time, lower start-up lost time and better amber time utilization. This leads to an increase of lane capacity at signalized intersections. The increase of lane capacity can also be affected by signal timing parameters. The assumption is that for traffic flows with lower G/C ratio, a lower start-up lost time and greater amber time utilization are achieved.

2. Literature review

In signalized intersection capacity analysis, researchers were mostly focused on a saturation flow value, rather than on the start-up lost time and amber time utilization. In general, *Highway Capacity Manual* (HCM, 2010) recommends 2 seconds as a default value of the start-up lost time. However, different authors considered the influence of various factors on the start-up lost time over the past few decades. Agent and Crabtree (1983) analyzed the factors related to start-up lost time and lost time at the end of the phase (or unutilized part of amber plus all-red), including the following: city size, location in a city, cycle length and the length of green, speed limit, gradient, vehicle type and turning maneuver, turning radius, distance from stop bar to intersection, and flow conditions. They found a strong correlation between start-up lost time and cycle length. For longer cycle lengths, start-up lost time tended to be much lower. Start-up lost time for longer cycle lengths was 40% lower than for shorter cycle lengths, from 1.42 to 0.85 s. In their study, the increased green time resulted in decreased start-up lost time, with approximately 50% difference between the longer and shorter green time, from 1.72 to 1.05 s. Their recommended base value for start-up lost time was 1.40 seconds with correction factors. In addition, a significant difference in start-up lost time in relation to flow conditions, was not detected. By analyzing the impact of various factors on the unutilized part of amber the authors concluded that lost time decreased as the cycle length increased (from 2.09 to 1.29), also with the increase of green time the unutilized part of amber decreased (from 1.94 to 1.35). They proposed the base value for ending lost time of 1.67 seconds, with adjustment factors. Both cycle length and green time summaries show that lost time decreases with the increase of time a driver must wait if he stops at the yellow light (Agent and Crabtree, 1983).

Bonneson (1993) realized that traffic pressure, measured by traffic volume per cycle had a statistically significant effect on discharge headway. An increase in traffic pressure resulted in a decrease in discharge headway, and therefore the start-up lost time. Bonneson (1993) also discovered a linear correlation between traffic pressure and start-up lost time. The author presented the average start-up lost time values, depending on the maneuver, 2.71 s for left and 2.13 s for right movement, based on research conducted at two intersections. Zhao et al. (2015) also determined that start-up lost time was correlated with queue length. For example, start-up lost time is 1.7 s and 3 s for queues with only 5 and 7 vehicles, respectively.

Recently, researches of amber time utilization are mostly oriented towards the red-light violation and traffic safety. Also, studies focus on defining the amber light dilemma zone, by analyzing the factors affecting it, and by defining the amber time duration. Modest number of authors has conducted research of amber time utilization in relation of signalized intersection capacity.

Agent and Crabtree (1983) concluded that green time and cycle length are actually related, but they weren’t able to determine which of the two was more accountable for start-up lost time variations. For this reason, the authors of this study have observed the effect of the *G/C* ratio on the start-up lost time and amber time utilization.

3. Data collection

The research of real start-up lost time and amber time utilization were carried out at 40 main intersections in Belgrade, with 300 lanes in total. The methodology was based on recording the time components of the queue discharge process in a period of one hour.

The following conditions are fulfilled in the research:

- Presence of the initial vehicle queue in each cycle,

- Uninterrupted queue discharge process,
- Different conditions of queue discharge in the research period,
- Standard traffic flow structure (commercial vehicle up to 10%),
- Standard intersection geometry.

Field data were collected by developed Android application for smart phones. For each cycle the following data were recorded:

- Start of a new cycle (the end of red for the observed flow),
- Moment of the first vehicle rear end passing over the stop bar,
- Moment of last vehicle rear end passing over the stop bar, and,
- Vehicle class.

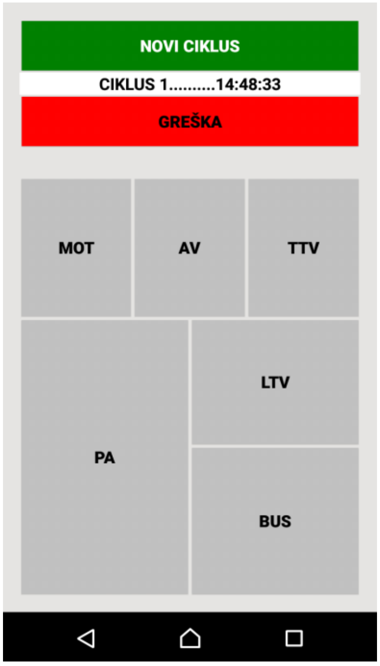


Fig. 2.
Developed Android application for field data collection
Source: Made by authors

Generated database for individual flow includes:

- Average start-up lost time

$$a = \frac{1}{n}\sum_{i=1}^{n} T1_i - \left(ER_i + ra\right) \tag{3}$$

- Average amber time utilization

$$b = \frac{1}{m}\sum_{i=1}^{m} T2_i - \left(ER_i + ra + Z_i\right) \tag{4}$$

- Green time share in the cycle

$$\lambda = \frac{G}{C} \tag{5}$$

- Saturated cycle share in the total number of cycles

$$X_c = \frac{m}{n} \tag{6}$$

Where: a: start-up lost time, b: amber time utilization, n: number of cycles, m: number of saturated cycles, ER: starting moment of red/amber, $T1$: moment of the first vehicle passing, $T2$: moment of the last vehicle passing, ra: red/amber duration (2 s).

4. Results

4.1. The influence of traffic flow conditions on the queue discharge process

To analyze the impact of flow conditions on the queue discharge process, traffic flows were classified by the ratio of saturated cycles in the total number of cycles X_c. Table 1 shows the average values of start-up lost time and amber utilization depending on X_c class. Start-up lost time declines from 1.98 s, when the saturated cycle ratio is lower than 10%, to 1.78 s when the ratio exceeds 90%. However, flow conditions have a greater impact on amber utilization, which increases from 0.31 s to a maximum 2.23 s. Figure 3b shows that amber time utilization reaches its maximum at X_c of 0.7-0.8, and then rapidly decreases. The reason for decline of amber time utilization at high levels of X_c can be explained by driver's assumption that congestion in the intersection's exit leg could provoke his staying in the conflict area of the intersection.
At higher X_c values, effective green time is greater than green time. The opposite can be concluded for lower values of X_c. The results show that effective green in comparison to green time varies in the range of -1.67 to +0.38 s.

Table 1
Effect of flow conditions on start-up lost time and amber utilization

X_c	<0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1
a **(s)**	1.98	1.94	1.84	1.90	1.77	1.80	no data	1.85	1.76	1.78
b **(s)**	0.31	1.05	1.11	1.36	1.20	1.61	1.75	2.23	1.71	1.35

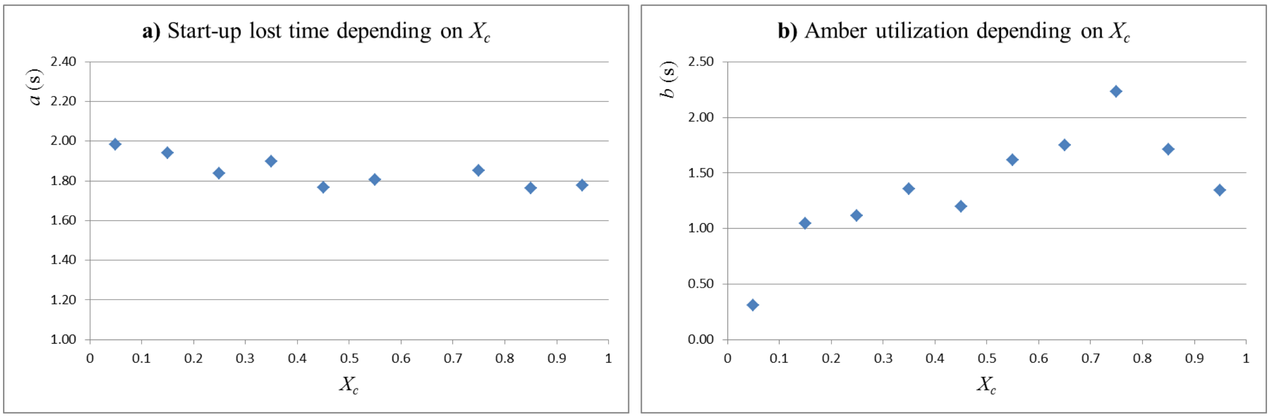


Fig. 3.
Effect of flow conditions on a) start-up lost time and b) amber time utilization
Source: Made by authors

4.2. The effect of signal timing parameters on queue discharge process

In this part the influence of *G/C* ratio, the parameter with largest effect on the lane capacity is discussed. Start-up lost time and amber time utilization are analyzed up to a value of *G/C* = 0.6. The *G/C* values higher than 0.6 occur in a small sample, so they are removed from further consideration.
As Table 2 shows, start-up lost time value increase rapidly to *G/C* = 0.3, followed by its relatively constant value. The increase of *G/C* ratio (Figure 4b) causes the reduction of amber time utilization, in the range of 2.26 s to 0.45 s. The highest amber time utilization is for *G/C* up to 0.1. In the next class (*G/C* 0.1-0.2) the value of amber time utilization rapidly decreases (1.35 s). With further increase of *G/C* occurs a constant, small decrease of the analyzed parameter.

Table 2
Effect of G/C on start-up lost time and amber time utilization

G/C	<0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6
a **(s)**	1.64	1.76	2.03	2.05	2.02	1.89
b **(s)**	2.26	1.35	1.30	0.69	1.00	0.45

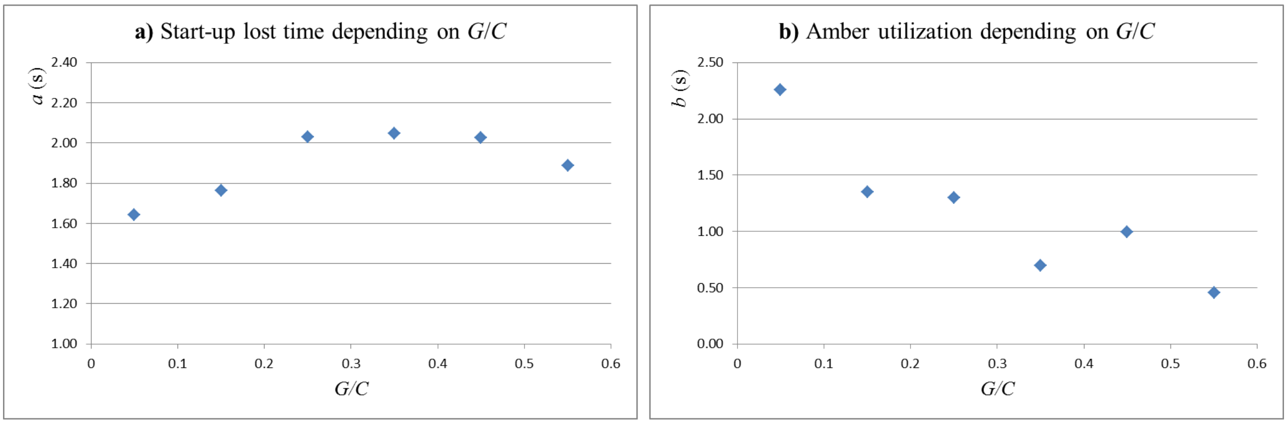


Fig. 4.
Effect of G/C on a) start-up lost time and b) amber time utilization
Source: Made by authors

5. Conclusions

The quality of signal timing optimization depends on the accuracy of input data, primarily saturation flow value and effective green time. This paper researches the effect of traffic flow conditions and signal timing parameters on start-up lost time and amber utilization. The research included 40 main intersections in Belgrade.
Based on results, a conclusion can be drown that start-up lost time is realized in a defined range (1.7 to 2.0 s), which corresponds to a value proposed by HCM 2010. Also, it was noticed that *G/C* ratio has larger impact on start-up lost time, especially for $G/C < 0.2$. The start-up lost time values for different X_c are relatively constant. However, the amber time utilization significantly depends on both analyzed parameters. At high X_c value (0.7-0.8) the amber time utilization is 2.25 seconds. The similar result is also obtained for the short green time duration ($G/C < 0.1$).
The difference between green and effective green is variable and depends on both observed parameters. In conditions in which $X_c > 0.7$, as well as for short green time duration, the effective green time can be larger than green, up to 0.5 s. For other combinations of values, the effective green is always smaller than green, up to 1.5 seconds. Therefore, it can be concluded that in signal timing optimization, traffic flows could be treated separately depending on degree of saturation and *G/C* ratio. For the flows with lower X_c and larger *G/C*, the effective green time value of up to 2 s lower in comparison to green time, should be adopted, and for the ones with higher X_c and lower *G/C*, the effective green time of up to 1 s higher. Precise determination of effective green time is particularly important for capacity estimation and signal timing optimization in saturated conditions.
Further research will be oriented towards the influence of driver behavior on start-up lost time and the impact of the start-up lost time on the queue discharge process, ie the saturated flow value. The future research should also analyze the combined impact of saturation flow and effective green on signalized intersection capacity variation.

Acknowledgements

This research was carried out within the Project TR36021, "The Effects of Global Challenges on Transportation Planning and Traffic Management in Cities", financed by the Ministry of Education, Science and Technological Development, Republic of Serbia.

References

Agent K.R.; Crabtree J.D.; 1983. *Analysis of Lost Times at Signalized Intersections*. Kentucky Transportation Center Research Report, Paper 964.
Akçelik, R. 1981. *Traffic signals: Capacity and timing analysis.* Australian Road Research Board. Research report ARR No. 123 *(7th reprint: 1998).*
Branston, D. 1979. *Some Factors Affecting the Capacity of Signalized Intersections*. Traffic Engineering and Control 20 (7/8), 390-396.
Čelar, N. 2007. *Contribution to the survey of design values of saturated flow at signalized intersections (in Serbian),* University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia.
Forschungsgesellschaft für Straßen und Verkehrswesen (Hrsg.) 2001. *Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS 2001),* FGSV Verlag GmbH, Köln, Germany.
National Research Council, 2010. *Highway Capacity Manual 2010,* Transportation Research Board, Washington D.C., U.S.A.
Webster, F.V.; Cobbe, B.M. 1966. *Traffic signals*, Her Majesty's Stationery Office, London.
Zhao, Y.; Zhang, W.; Lu, J.; Wenjun Zhang, W.; Ma, Y. 2015. Estimation of Saturation Flow Rate and Start-Up Lost Time for Signal Timing Based on Headway Distribution, *Discrete Dynamics in Nature and Society*, 1-7.

ESTIMATION OF TURBO-ROUNDABOUT CAPACITY

Janusz Chodur[1], **Mariusz Kiec**[2]
[1,2] Institute of Road and Railway Engineering, Cracow University of Technology, Poland

Abstract: In recent years, a new estimation method of lane capacity at turbo-roundabouts entries in various countries has been developed. It can be shown that methods developed under different assumptions and taking into account various factors determining capacity give significantly different results. Different approaches to the estimation of capacity are used, i.e.: stream conflict models (regression models) and gap acceptance models with behavioural parameters. The values of parameters in models reflect local research conditions. Therefore, the direct application of empirical findings on another area (country) may cause an unspecified inaccuracy. The authors conducted a comparison of capacity estimation models, i.e.: those developed by Fortuijn and Harte, HCM-2010 Hagring and Fisk, and Brilon and Wu, in order to indicate differences of estimated capacity. The paper also presents research conducted in Poland, including: parameters of the gap acceptance capacity model (critical headway, follow-up headway) as well as characteristics of a roundabout circulating stream. These parameters were used in a comparative study of models which are used in various countries to estimate the capacity of roundabout entries. The main aim of this research is the development of an estimation capacity method for practical applications in Poland. The findings and analyses are promising, but they indicate a need for continued research, in particular in behavioural parameters of the gap acceptance model.

Keywords: capacity, turbo roundabout, gap acceptance model, critical headway, follow-up headway.

1. Introduction

Turbo roundabouts are a relatively new form of intersections. They are characterised by the ability to direct different traffic routes through the intersection, using more than one lane. The vehicles in the particular movements pass through the intersection without having to change lanes. Cross-sections of the roadway of a roundabout, which can have between one and three lanes in various places, are adapted to the traffic volume of each movement. Spiral marking can be seen on the roadway of the roundabout, often accompanied by a physical separation of traffic lanes by means of raised dividers. It is supposed to rule out the unnecessary changing of lanes on the roundabout's roadway which increases the traffic safety hazards. The edges of the central island and of the traffic lanes on the roundabout's roadway are shaped using sections of a circle, the Archimedean spiral or an ellipse (Giuffre et al. 2009; Royal Haskoning DHV, 2009).

Due to the lack of Polish design guidelines for turbo-roundabouts in Poland, they are designed using foreign legislation and guidelines (Royal Haskoning DHV, 2009; Brilon, 2014; Haller, 2015). This results in a diversity of solutions used in different regions of the country. One of the problems related to implementation is the need to use foreign methods of assessing performance, which do not take into account the behaviours of Polish drivers. Polish methods of calculating the capacity of intersections including roundabouts, do not cover turbo-roundabouts due to the period of their development between 2001 and 2004 (Tracz et al. 2004). It can easily be demonstrated that foreign methods of assessing traffic performance, developed with different assumptions and taking into account determining various factors, yield significantly different results. The parameters of the gap acceptance capacity model in the circulating flow rate have values representing the area of study. Thus, the direct application of a selected method in conditions other than those in the test area, may be subject to an undefined inaccuracy. In the recent years, empirical studies have been undertaken in Poland, mainly focusing on behavioural parameters for the turbo-roundabout entry capacity estimation models (Macioszek, 2013; Chodur and Ostrowski, 2015). These studies and the conducted comparative analyses of different models have allowed for the development of hints for estimating the capacity of turbo-roundabouts.

2. Capacity models of turbo-roundabouts

Models used to calculate the capacity of turbo-roundabouts can be divided into three types: models of conflicting streams, gap acceptance models and simulation models. Models of conflicting streams are also known as empirical models. The linear or exponential relationship between the capacity of entries and traffic volume on the roadway of a roundabout is determined based on observations. The advantages of these models are: the ability of direct application of the results of the measurements carried out in the conditions of saturated traffic, and taking into account the so-called pseudo-conflict in the calculation (the impact of vehicles non conflicting – leaving the roundabout – with the stream of vehicles entering the roundabout on the capacity of the entry). Among the disadvantages of this method one can name: its inability to identify the relationship between traffic volume on entries and traffic volume on the roadway of a roundabout when there is no saturated traffic, as well as the ability to estimate only a simple relationship between the capacity of entries and traffic in the roundabout. The first model allowing to estimate the capacity of entries in turbo-roundabouts was the model of Fortuijn and Harte based on a modification on Bovy's model, and it was designed to estimate the capacity of one- and two-lane roundabouts (Fortuijn, 2009).

$$C_{El} = C_{0l} - b_{\min} \cdot Q_{R,\min} - b_{\max} \cdot Q_{R,\max} - a_{lu} \cdot Q_{Su} \tag{1}$$

[1] Corresponding author: jchodur@pk.edu.pl

$$C_{Er} = C_{0r} - b_{ru} \cdot Q_{Ru} - a_{ru} \cdot Q_{Su} \tag{2}$$

where:

- C_{El}, C_{Er} – capacity of left/right entry lane [pcu/h],
- C_{0l}, C_{0r} – capacity of left entry lane (left/right) without traffic on circulating lane [pcu/h]
- $Q_{R,\min}$, $Q_{R,\max}$ – circulating traffic volume on lane with the lower/higher traffic volume [pcu/h],
- Q_{Su} – exiting traffic volume [pcu/h],
- a_{lu}, a_{ru} – effect of exiting traffic on the capacity of the left/right entry lane [-]
- $b_{\min}$, b_{max} – effect of roundabout lane with the lower/higher traffic volume on the capacity of left entry lane [-]; b_{min}=0.68
- b_u – effect of outer roundabout lane on the capacity of right entry lane.

Another example of the empirical model is the exponential relation between the capacity of the lane on the entry and the traffic volume of the roundabout roadway as applied in HCM 2010 method.

$$C_j = A \cdot e^{-B \cdot Q_R} \tag{3}$$

where:

- C_j – capacity of j entry lane [pcu/h],
- A – capacity of entry lane without traffic on circulating lane [pcu/h],
- B – impact of the lane configuration on the roundabout inlet and roadway,
- Q_R – conflicting flow rate [pcu/h].

With the most extended theoretical and empirical background, gap acceptance models have recently been most often applied. Their theoretical rudiments are based on the analysis of driver behaviours entering to the conflicting flow rate from the conficting stream. Apart from the circulating traffic volume (on the roundabout roadway) Q_R, other key variables, which constitute this type of models, include: critical headways for circulatory lane t_c and follow-up time for queuing vehicles t_f, which indicate drivers' behaviour when entering the roundabout and the minimum distance between vehicles on the roadway of a roundabout t_m.

Gap acceptance models include a model designed by Hagring in 1998, constituting the extension of the earlier model by Troutbeck (1986) modified then by Fisk (1989) (Fortuijn, 2009).

The conversion of these models gave rise to the Brilon-Wu model enabling the calculation of a two-lane roundabout capacity; presently the model is used as part of a practical method of calculating the capacity of turbo-roundabouts in the following form (Haller, 2015):

$$C_j = \frac{3600}{t_f} \cdot \left(1 - \frac{t_m \cdot Q_{Ru}}{3600}\right) \cdot \left(1 - \frac{t_m \cdot Q_{Ri}}{3600}\right) \cdot exp\left(-\frac{Q_{Ru} + Q_{Ri}}{3600} \cdot \left(t_c - \frac{t_f}{2} - t_m\right)\right) \tag{4}$$

where:

- C_j – capacity of j entry lane (PCU/h),
- Q_{Ri}, Q_{Ru} – circulating traffic volume on inner/outer lane [PCU/h],
- t_c – critical gap for vehicles entering circulatory lane j [s],
- t_f – follow-up time, depending on which circulatory lane j entering vehicle has to merge into [s],
- t_m – minimum gap between vehicles in major circulating traffic [s],

Based on empirical studies conducted in Poland (Macioszek, 2013), a model of entry capacity was developed for different configurations of turbo-roundabout lanes. Below there is a formula for the left lane of a two-lane entry of a turbo-roundabout with two priority lanes:

$$C_{El} = \begin{cases} \dfrac{a \cdot 3600}{t_f} & \text{for} \quad Q_R = 0 \text{ pcu/h} \\[2ex] \dfrac{a \cdot 3600 \cdot e^{-\left(\frac{Q_{Ri} \cdot}{3600 - Q_{Ri} \cdot t_{mi}} + \frac{Q_{Ru} \cdot}{3600 - Q_{Ru} \cdot t_{mu}}\right) \cdot (t_{cl} - t_{mi})} \cdot \left(\frac{Q_{Ri} \cdot}{3600 - Q_{Ri} \cdot t_{mi}} + \frac{Q_{Ru} \cdot}{3600 - Q_{Ru} \cdot t_{mu}}\right)}{\left(1 - e^{-t_{fl} \cdot \left(\frac{Q_{Ri} \cdot}{3600 - Q_{Ri} \cdot t_{mi}} + \frac{Q_{Ru} \cdot}{3600 - Q_{Ru} \cdot t_{mu}}\right)}\right) \cdot \left(1 + \frac{t_{mi} \cdot Q_{Ri} \cdot}{3600 - Q_{Ri} \cdot t_{mi}}\right) \cdot \left(1 + \frac{t_{mu} \cdot Q_{Ru} \cdot}{3600 - Q_{Ru} \cdot t_{mu}}\right)} & \text{for} \quad 1 < Q_R \leq 100 \text{ pcu/h} \\[2ex] \dfrac{a \cdot 3600 \cdot \phi_i \cdot \phi_u \cdot e^{-\left(\frac{\phi_i \cdot Q_{Ri} \cdot}{3600 - Q_{Ri} \cdot t_{mi}} + \frac{\phi_u \cdot Q_{Ru} \cdot}{3600 - Q_{Ru} \cdot t_{mu}}\right) \cdot (t_{cl} - t_{mi})} \cdot \left(\frac{\phi_i \cdot Q_{Ri} \cdot}{3600 - Q_{Ri} \cdot t_{mi}} + \frac{\phi_u \cdot Q_{Ru} \cdot}{3600 - Q_{Ru} \cdot t_{mu}}\right)}{\left(1 - e^{-t_{fl} \cdot \left(\frac{\phi_i \cdot Q_{Ri} \cdot}{3600 - Q_{Ri} \cdot t_{mi}} + \frac{\phi_u \cdot Q_{Ru} \cdot}{3600 - Q_{Ru} \cdot t_{mu}}\right)}\right) \cdot \left(\phi_i + \frac{\phi_i \cdot t_{mi} \cdot Q_{Ri} \cdot}{3600 - Q_{Ri} \cdot t_{mi}}\right) \cdot \left(\phi_u + \frac{\phi_u \cdot t_{mu} \cdot Q_{Ru} \cdot}{3600 - Q_{Ru} \cdot t_{mu}}\right)} & \text{for } Q_R > 100 \text{ pcu/h } \wedge Q_R < C_R \\[2ex] \cong 0 \text{ pcu/h} & \text{for} \quad Q_R \cong C_R \end{cases} \tag{5}$$

where:

- C_{El} – base capacity for left lane on entry [pcu/h],

Φ – share of vehicles in free flow speed [-],
a – a parameter depending on the configuration of the traffic lanes and the presence of separators [-]
i, u – indices for the circulatory lanes; inner/outer,
– other markings as in the formula (4).

In the above model, behavioural parameters t_c and t_f depend on the average speed on the roundabout roadway and this is, in turn, a function of the base radius of the roundabout roadway, R_1 (Giuffrè et al. 2009). The minimum headway t_m between vehicles on the roundabout roadway depends on the traffic volume on this lane as well as the share of vehicles in free flow speed ϕ.
The values of parameters t_c, t_f and t_m depend in general on the configuration of lanes on the roundabout entry and on the roundabout roadway by the entry. In addition to the circulating traffic volume, provided it is properly determined and recognised by the model (the share of vehicles in free flow or non free flow and the distribution of headways), the above parameters are of key importance in the process of determining the correct estimation for the capacity of a roundabout entry lane.
Figure 1 shows a comparison between the capacity of a left lane on a two-lane roundabout entry with two priority lanes determined based on models (1), (3), (4) and (5). The following data have been taken into account in the calculations:
model (1) - $Q_{Ri} = Q_{RU} = 0.5\ Q_R$, $a_{lwl} = 0.21$, $a_{pwl} = 0.14$, $b = 0.68$, $b_{\max} = 0.82$; a) traffic volume of the stream leaving the roundabout $Q_{Su} = 0.4\ Q_R$, b) the stream leaving the roundabout has been omitted.
model (3) - $A = 1130$ pcu/h, $B = 0.75{\cdot}10^{-3}$,
model (4) - $Q_{Ri} = Q_{RU} = 0.5\ Q_R$, $t_c = 4.0$ s, $t_f = 2.6$ s, $t = 1.9$ s,
model (5) - $Q_{Ri} = Q_{RU} = 0.5$, $\phi_{Rl} = \varphi_{Ru} = 1.0$ - 0,64 $R_1 = 20$ m; (a) with dividers $v = 31{,}9$ km/h, $t_c = 4{,}2$ s, $t_f = 3{,}3$ s, $a = 1.02$; (b) without dividers $v = 33{,}5$ km/h, $t_c = 3{,}9$ s, $t_f = 2{,}9$ s, $a = 1{,}01$

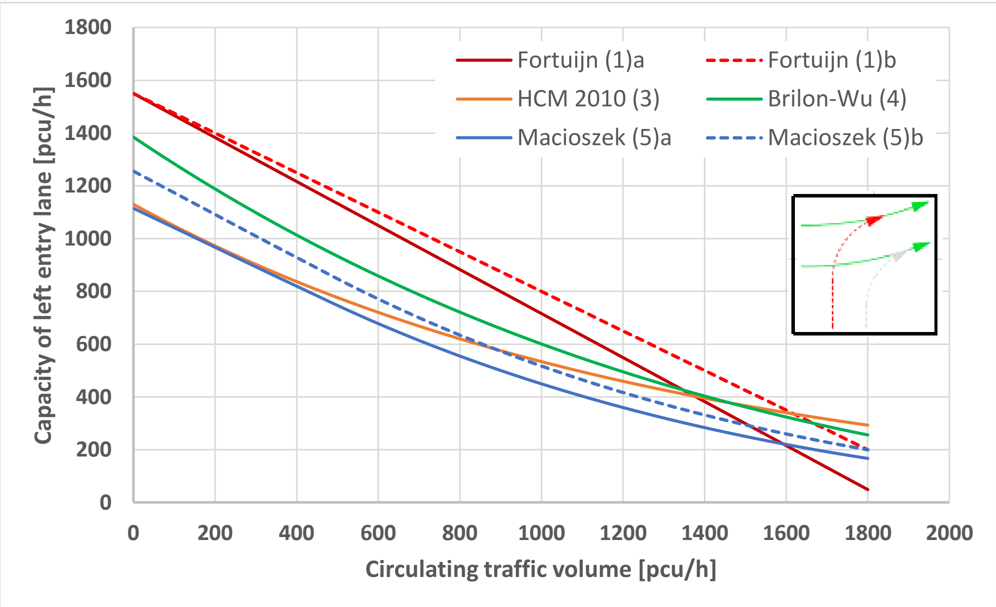


Fig. 1.
Comparison of the left lane inlet capacity on a turbo-roundabout based on various models

The graph shows the extent of diversification of capacity values estimated using various methods. The straight-line graph representing the capacity estimation based on model (1) stands out from the rest. It should be noted that the rate of the decline in capacity depends in this case not only on the traffic volume on the roundabout, but also on the traffic volume of the stream leaving the roundabout roadway (lines (1)a and (1)b). A similar shape of curves was generated by the gap acceptance capacity model in conflicting flow rate (4) and (5), although model (4) and parameters determined in Germany offer greater values of capacity. According to (Macioszek, 2013) research, model (5), using dividers significantly reduces the speed of vehicles on a roundabout roadway and decreases the capacity of the entry (curves (5)a and (5)b).

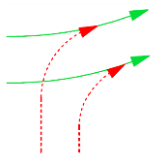
3. The research on the parameters in models estimating turbo-roundabout capacity

In gap acceptance models, there are assumptions and parameters which are significant for the correct mapping of this process. These assumptions relate mainly to the representation of the circulating flow, primarily the distribution of headways with the appropriate parameters, and, in addition, in some models involving vehicles moving in free and non free flows. The parameters describing the behaviour of traffic participants who join or intersect the circulating flow constitute a separate group. The distributions of headways in the flow on the roundabout roadway are often modelled using the exponential distribution, shifted exponential distribution and Cowan's M3 distribution, or spline functions from several distributions. The simplest exponential distribution, with one parameter, can be used to describe headways on a single lane only at low traffic volumes and to describe a complex major stream, for example, on two lanes of the roadway jointly. The shifted exponential distribution, with an additional parameter, which is the minimum headway, eliminates from the model very small, unrealistic headways on a single lane that can occur when using exponential distribution. At higher traffic volumes, not all vehicles moving in free flow (randomly), so it is advisable to distinct the free and non free parts of the traffic. This entails the need to define an additional parameter, which is the share of vehicles in free flow (Cowan's distribution) or of additional parameters (e.g. minimum headways) for the description of free and non-free parts (complex distributions, e.g. Hyper-Erlang distribution) (Chodur 2007, Macioszek, 2013). Research and analyses concerning the description of the flow of vehicles on the roadway of various types of roundabouts are described in the work (Macioszek, 2013; Brilon and Geppert, 2014).

The approval process model requires the specification of two parameters, i.e the critical headways t_c, which is the minimum time interval between vehicles in the circulating flow, which can be used by the average (in the statistical sense) driver from minor entry for the intended manoeuvre, and the follow-up time t_f, with which vehicles from the queue at the minor entry enter the intersection one by one when the headways in the circulating flow allows more than one vehicle to enter. Research and analyses of these parameters were carried out in recent years, among others at the Cracow University of Technology. Research was carried out on eight roundabouts (19 entries) with the use of the video registration technique. The values for critical headway t_c were determined using the method of maximum likelihood (Brilon et al. 1997; Brilon and Geppert, 2014) based on a set of pairs of values of headways between vehicles in the major flow: the used one and the largest discarded one for each vehicle which stopped at the entry and then pulled into the roundabout roadway. The values of follow-up headway t_f have been designated as the arithmetic mean of the registered headways from the queue at the entry entering the roundabout roadway when the headways in circulating flow allowed more than one vehicle from the queue to enter. Most often, the test results of these parameters are aggregated to the individual configurations of the traffic lanes on the entries of turbo-roundabouts. They can also be dependent on geometric features of a given roundabout. An example of such a relation is the model listed in (Macioszek, 2013):

Table 1

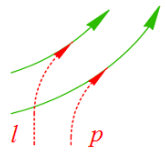
t_c and t_f models for two-lane entry with two priority lanes (Macioszek, 2013)

Diagram	Lane	Critical headway t_c (s)	Follow-up headway t_f (s)
	Roundabout with dividers		
	Left lane	$-0.0002\bar{V}^2 - 0.032\bar{V} + 5.3795$	$-0.0003\bar{V}^2 - 0.1346\bar{V} + 7.8901$
	Right lane	$-0.0003\bar{V}^2 - 0.0045\bar{V} + 4.5601$	$-0.0007\bar{V}^2 - 0.0974\bar{V} + 6.9869$
	where: $\bar{V} = -0.001R_1^2 + 0.7622R_1 + 17.038$ [km/h] speed on the roundabout roadway		
	Roundabout without lane dividers		
	Left lane	$-0.0001\bar{V}^2 - 0.0297\bar{V} + 5.0352$	$-0.0001\bar{V}^2 - 0.1154\bar{V} + 6.8691$
	Right lane	$-0.0004\bar{V}^2 - 0.0034\bar{V} + 4.5492$	$-0.0004\bar{V}^2 - 0,0813\bar{V} + 5.8799$
	where: $\bar{V} = -0.001R_1^2 + 0.8672R_1 + 16.521$ [km/h] speed on the roundabout roadway		

In that model, the base radius of the turbo-roundabout R_1 (Macioszek, 2013) determines the average speed on the roundabout roadway $\bar{V}$, which, in turn, determines both parameters of the gap acceptance process t_c and t_f.

An example list of the obtained values of parameters t_c and t_f is presented in Table 2. The values of critical headways t_c obtained from the measurements conducted by the authors turned out to be larger than the values calculated from the relations provided in (Macioszek, 2013) (Table 2). This is mainly due to the applied method of determining t_c. In own studies, it was the method of maximum likelihood, while in (Macioszek, 2013) these were much earlier methods of cumulative curves for accepted and rejected headways, and the acceptance curve method. Critical headways determined by different methods differ by more than 1 second (Patil and Pawar, 2014).

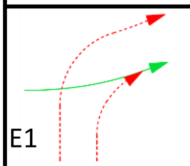
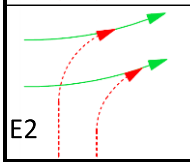
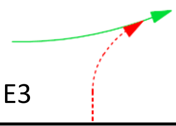
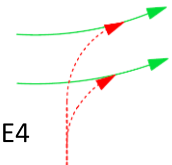
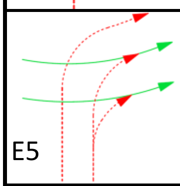
Table 2
Critical headways t_c and follow-up times t_f obtained from own studies (CUT) and calculated according to relations provided in (Macioszek, 2013)

Configuration of lanes	Lane	No.[1)]	Critical headway t_c [s]			Follow-up time t_f [s]		
			Number[2)]	CUT[3)]	EM[4)]	Number	CUT	EM
	*l*	1	2179 ; 1234	**4.669**	3.864	1139	**3.02**	2.311
	l	2	721 ; 789	**4.863**	3.864	2898	**2.95**	2.311
	l	3	318 ; 151	**4.721**	4.066	25	**3.00**	2.845
	l	4	1134 ; 854	**5.064**	3.700	662	**2.66**	1.891
	l	5	843 ; 632	**4.862**	3.716	424	**2.72**	1.931
	p	1	312 ; 382	**4.784**	3.849	1064	**2.70**	2.666

[1)] – number of measurement site
[2)] – headways rejected ; headways accepted
[3)] – own research
[4)] – values calculated based on (*Macioszek, 2013)*

Table 3 summarises the results of the research parameters t_c and t_f conducted in Germany (Brilon and Geppert, 2014) as well as own research from the period 2013 – 2016. The range of values obtained in the research of the values of the parameters was provided in brackets, while the values recommended in the German method (Haller, 2015) were given in bold. In own research, values calculated as a weighted average (sample sizes were adopted as the weight) were also given in bold.

Table 3
Values of t_c and t_f [s] obtained in German research (Brilon and Geppert, 2014) and in own study

Type of entry	Lane	German research		Polish research			
		t_f	t_c	t_f	N	t_c	N
 E1	L	(2.4 – 2.6) **2.5**	(4.0 – 5.3) **4.5**	(2.2 – 2.8) **2.6**	3879	(4.0 – 5.8) **4.7**	3883
	P	(2.4 – 2.5) **2.5**	(3.9 – 4.6) **4.5**	(2.4 – 3.1) **2.7**	4494	(3.8 – 5.0) **4.4**	3807
 E2	L	(2.6 – 2.7) **2.6**	(3.9 – 4.0) **4.0**	(2.7 – 3.2) **2.9**	5625	(4.1 – 5.4) **4.9**	3539
	P	(2.5 – 2.7) **2.7**	(4.5) **4.5**	(2.6 – 3.2) **2.7**	1718	(4.8 – 5.7) **5.1**	641
 E3		(2.4) **2.5**	(4.5) **4.5**	2.7 (Tracz et al. 2004)	–	4.5 (Tracz et al. 2004)	–
 E4		(2.7 – 2.9) **2.8**	(4,2 – 4.5) **4.3**	(2.5) **2.5**	150	(3.3– 4.1) **3.9**	388
 E5	L	–	–	(2.7) **2.7**	190	(3.9 – 4.1) **4.0**	308
	P	–	–	–	–	–	–

N denotes the sample size.

As is apparent from the values in Table 3, the Polish research featured a larger range of variability both in the values of t_c and t_f obtained on particular roundabouts. Based on the German and Polish research, the recommended values of t_f differ by up to 0.3 s, while for the left lane of the E2 configuration a larger value was obtained in the Polish research, whereas for the E4 configuration – a smaller value was obtained. This gives a difference in capacity of around 150 pcu/h with Q_R = 0 pcu/h. The diversity of t_f can also be influenced by such factors as the radius of the entry, the vehicles leaving the roundabout (especially with a high proportion of heavy vehicles) and weather conditions (Fortuijn, 2009).

With regard to t_c, the recommended values differ by up to 0.9 s and this applies to the left lane at the entry to a roundabout with E2 configuration. When it comes to the German results, what is interesting is that t_c for the left lane of E1 configuration equals 4.5 s, while for E2 configuration it equals 4.0 s. In the first case, the vehicles of the entry cross only the circulating flow, while in the second case they cross the stream on the outer lane and merge into the stream on the inner lane of the roundabout roadway. In the Polish studies the obtained values were, respectively, 4.7 s (E1) and 4.9 s (E2). The diversity of values of t_c for the right lane of configurations E1 and E2 in the Polish research can be explained by the influence of vehicles in the inner lane of the roundabout roadway on the vehicles merging into the stream on the outer lane (pseudo-conflict) with E2 configuration.

4. The choice of models for practical applications

The gap acceptance capacity models in the circulating flow have often been used in various applications. They are easily adaptable due to the selection of appropriate parameters and their calibration. Numerous varieties of acceptance models, with more or less complex description of the circulating flow, enable the adaptation of the already existing models to current solutions, especially where the implementation of the research programme on intersection capacity requires a longer time. The research projects carried out by the Cracow University of Technology in the period of 2013 – 2016 included the study of behavioural parameters as well as the research on the turbo-roundabout entry capacity. The maximum number of vehicles (capacity) entering the roundabout from a given entry lane on the roundabout roadway can be determined during the periods of traffic saturation (the period when vehicles queue before entering the roundabout). Due to the adaptation to the needs of traffic as well as their traffic performance, turbo-roundabouts have no queues in the area of entries. Queues forming by entries are usually short-term. This entails the need to count vehicles with a right of way as well as entering the roundabout in short intervals. Of course this implies a significant dispersion of values in the capacity of recalculated within an hour. An interval assumed in the reaserch carried out by Cracow University of Technology amounted to 30 s. The same interval was applied in descriptive studies presented in (Brilon and Geppert, 2014).
Figure 2 shows the average values of the left lane capacity on the entry with E2 configuration based on observations in 30 s intervals. The dependence of the capacity on the major traffic volume on the roundabout roadway has been represented in the figure by a broken line (exponential function).

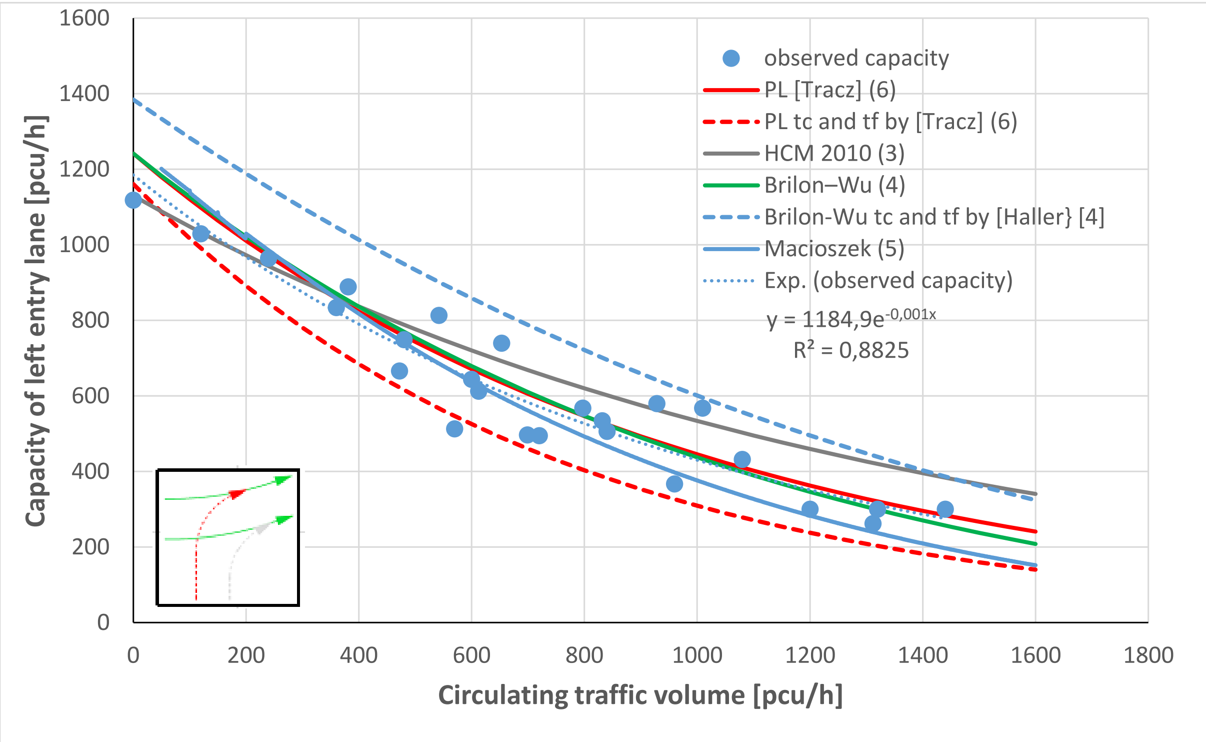


Fig. 2.
Empirical capacities for the left lane on E2 turbo-roundabout inlet and capacity curves according to various models

Also the capacity model for the intersection entry without traffic lights is possible to applying for describing the dependence between the capacity of the left lane and traffic volume on the roundabout roadway (Tracz et al. 2004). In the case of an intersection with the right of way, the equivalent of the analysed relation of the left two-lane E2 turbo-roundabout entry is the movement of turning left from the minor entry. In both cases the analysed movement crosses the priority lane and joins in the traffic on the other lane. The difference in operation for these two cases concerns traffic directions on the road with the right of way and the perception of the flow of vehicles with the right of way.

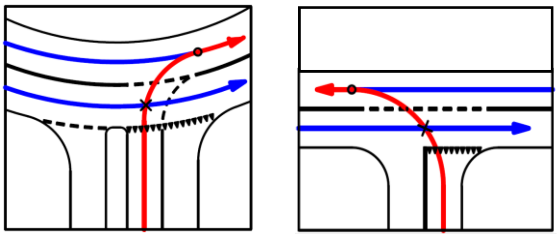


Fig. 3.
Analogical manoeuvres on the roundabout and three-inlet intersection with the right of way

The capacity model in the method (Tracz et al. 2004) is represented as follows:

$$C_l = \frac{3600}{t_f} \cdot e^{-1{,}07 \cdot \frac{Q_R}{3600} \cdot \left(t_c - \frac{t_f}{2}\right)} \quad \text{[pcu/h]} \tag{6}$$

symbols as in previous formulas.

In all capacity estimation models compared with empirical data, the values of parametres t_c and t_f were determined in own research (table 3 – t_c = 4,9 s, t_f = 2.9 s). For the remaining parameters, the values recommended for particular methods were assumed (description before Figure 1). The distribution of traffic on the roundabout lanes was assumed to equal 50%. The matching of particular curves to empirical capacity (Figure 2) was assessed with the help of the root mean square error – RMSE).

Table 4
Root mean square error values for capacity estimation using various methods

Method	**Polish (Tracz et al. 2004) (6)**	**Brilon–Wu (4)**	**Macioszek (5)**	**HCM 2010 (3)**
RMSE [pcu/h]	78.9	80.6	179.4	105.5

As evidenced by results, models (6) and (4) show the best match, with an almost identical error. It should be noted that model (6) is applied in the method of calculating capacity of intersections with a right of way and it is for those intersections that it was calibrated. The application of this model with parameters t_c and t_f determined for turbo-roundabouts yielded a positive result. For comparative purposes, the graph (Figure 2) also includes curves (broken lines) according to models (6) and (4) with values of parameters t_c and t_f recommended, respectively, in the Polish method: for a left turn from the minor entry of an intersection situated in a small locality (t_c=6.3 s and t_f=3.2 s), and in the German method: for a left lane of a two-lane entry of a turbo-roundabout with two priority lanes (E2). In this case, the Polish method gives a significantly lower lane capacity, while the German one gives a significantly higher one.

5. Conclusions

Capacity models for entry lanes on turbo-roundabouts which have been designed and applied in various countries make use of a different number of parameters (from 2 – (6) model, to 6 – (5) model). This diversity and parameter values determined in a given country yield a relatively large scope of estimated capacities for a given entry configuration and determined circulating traffic volume. A direct use of a given method in different conditions (in a different country) may lead to unspecified inaccuracies in capacity estimations.

Thanks to the authors' research it was possible to determine empirical capacity and values of key parameters t_c and t_f of the gap acceptance model for different configurations of turbo- roundabout entries in Poland. The values t_c and t_f differ from those established in German studies (Brilon and Geppert, 2014; Haller, 2015). It is down to specific behavioural patterns of drivers using turbo-roundabouts in these two countries. Polish drivers are usually very cautious while entering such intersections. Turbo-roundabouts are not yet a common type of an intersection, and traffic rules are quite different from those on single or two-lane roundabouts.

The reference to the estimated capacity with the use of various models dedicated to turbo-roundabouts as well as the model designed for intersections with the right of way, showed that it is possible to use for calculation both Brilon-Wu (4) model as well as the Polish one (6) (Tracz et al. 2004), provided that they assume behavioural parameters indicated in the authors' own analyses. These findings are related to the left lane on two-lane turbo-roundabout entry with two priority lanes presented in this article. Further research and analysis should enable the equivalent calculations for every individual lane and entry configurations.

References

Brilon, W. 2014. Roundabouts: a State of the Art in Germany. In *Proceedings of the 4th International Conference on Roundabouts, Transportation Research Board (TRB), Seattle.*

Brilon, W.; Geppert, A. 2014. *Verkehrsablauf und Verkehrssicherheit an zweistreifig befahrbaren Kreisverkehren und Turbokreisverkehren*. Forschung Straβenbau und Straβenverkehrstechnik, Heft 1112.

Brilon, W.; Koenig, R.; Troutbeck, R.J. 1997. Useful estimation procedures for critical gaps. In *Proceedings of the Third International Symposium on Intersections without Traffic Signals*, Portland, Oregon, USA.

Chodur, J. 2007: *Funkcjonowanie skrzyżowań drogowych w warunkach zmienności ruchu (Operating of road intersections in conditions of traffic variability)*. Politechnika Krakowska, seria Inżynieria Lądowa, 347: 1-205.

Chodur, J.; Ostrowski, K. 2015. *Unsignalised intersection capacity and performance estimation methods*. Road and transportation Engineering, Seria Inżynieria Lądowa, Politechnika Krakowska, 483: 15-32.

Fortuijn, L.G.H. 2009. Turbo Roundabouts: Estimation of Capacity, *Transportation Research Record Journal of the Transportation Research Board*, 2130: 83-92.

Giuffrè, O.; Guerrieri, M.; Granà, A. 2009. *Turbo-roundabout general design criteria and functional principles: case studies from real world*. Department of Road Infrastructure Engineering degli Studi di Palermo, Viale delle Scienze al Parco d'Orleans, Palermo.

Haller, W. (Leiter). 2015. *Arbeitspapier. Turbokreisverkehre*., FGSV, 1-27.

Macioszek, E. 2013. *Modele przepustowości wlotów skrzyżowań typu rondo w warunkach wzorcowych (Models of traffic capacity in roundabouts inlets in ideal conditions)*. Open Access Library, 3(21): 1-260.

Patil, G.R.; Pawar, D.S. 2014. *Temporal and Spatial Gap Acceptance for Minor Road at Uncontrolled Intersections in India*. TRB 93rd Annual Meeting Compendium of Papers, Paper Numbers: 14-4837.

Royal Haskoning DHV. 2009. *Roundabouts - Application and design. A practical manual*. Ministry of Transport, Public Works and Water management, Partners for Roads.

Tollazzi, T.; Mauro, R.; Guerrieri, M.; Renčelj, M. 2016. Comparative Analysis of Four New Alternative Types of Roundabouts: "Turbo", "Flower", "Target" and "Four-Flyover" Roundabout. *Periodica Polytechnica, Civil Engineering*, 60(1): 51-60.

Tracz, M.; Chodur, J. et al. 2004. *Metoda obliczania przepustowości rond (The method of capacity counting of roundabouts)*. Generalna Dyrekcja Dróg Krajowych i Autostrad (General Director for National Roads and Motorways), Warszawa, 1-76.

EVALUTION OF THE EFFECT ON THE LAYER THICKNESS OF DIFFERENT LAYER DESIGNS

Ahmet Ünal[1], Muhammed Yasin Çodur [2], Merve Gülfer Özcan[3]
[1,2,3] Erzurum Technical University, Engineering and Architecture Faculty, Department of Civil Engineering, Erzurum, Turkey

Abstract: Road pavement design is carried out by estimating the expected traffic density during the project. According to these estimations material properties of the layer and layer thickness are determined. Pavement project should be carried out so as not to allow the formation of cracks and large deformation beyond permissible limits. Road pavement consists of gravel with asphalt concrete and base layer thickness. In case of undesired deformations pavement cracks occur in the pavement design and implementation of the scientific method. In this study layer thickness calculation and selection of material properties belonging to the layers used in Erzurum South Ring Road that was built in respect to American Association of State Highway and Transport Officials (AASHTO-86) were analysed. Other pavement designs that could be alternative to the same road were investigated in terms of layer thickness and economic analyses.

Keywords: AASHTO-86 method, flexible pavement, layer thickness.

1. Introduction

Road body consists of two main parts which include infrastructure and superstructure. Infrastructure is called as a term between constructions completed on leveling a road surface and the natural ground line. Road infrastructure provides a smooth surface elevation and loads from the infrastructure layer are built to be spread over a larger area (Saltan et al. 2002). The road superstructure provides vehicles with smooth rolling surface and is built to transfer loads from superstructure to the infrastructure. Road superstructure consists of three parts which are surface, base and subbase layers (Pavement Interactive, 2008).
The main purpose of the pavement design is to predict from traffic loads stress and to reduce limit value of infrastructure capacity. Moreover, it is important that design of layer thickness should not allow to any deformation. There are 3 different flexible design method which are empirical, analytical and empirical-analytic method (Kok, 2008). In our country, American Association of State Highway and Transport Officials (AASHTO-86) method is used which are based partly empirical partly by the analytical methods of layer thickness of road is designed length of service and economic efficiency of the road, subgrade bearing capacity and are designed using passed over to the amount of traffic and axle loads.

2. Literature review

Before the 1920s, pavement design mainly consisted of defining thicknesses of layered materials that would provide strength and protection to a soft, weak subgrade. Pavements were designed against subgrade shear failure. Engineers used their experience based on successes and failures of previous projects. As experience evolved, several pavement design methods based on subgrade shear strength were developed. The Asphalt Institute (AI) Method (Asphalt Institute, 1982, 1991) and the Shell Method (Claussen et al., 1977; Shook et al., 1982) are samples of procedures based on asphalt concrete's fatigue cracking and plastic deformation failure modes. These methods were the first to use linear-elastic theory of mechanics to compute structural responses (in this case strains) in combination with empirical models to estimate number of loads to failure for flexible pavements. The American Association of State Highway Officials (AASHO) Road Test in 1960s was a seminal experiment from which the AASHTO design guide was developed.
New design criteria were required to incorporate such failure mechanisms (e.g., fatigue cracking and permanent deformation in the case of asphalt concrete). The Asphalt Institute Method (Asphalt Institute, 1982, 1991) and The Shell Method (Claussen et al., 1977; Shook et al., 1982) are samples of procedures based on asphalt concrete's fatigue cracking and plastic deformation failure modes. These methods were the first to use linear-elastic theory of mechanics to calculate structural responses (in this case strains) in combination with empirical models to estimate number of loads to failure for flexible pavements.
The first empirical methods for flexible pavement design date to the mid-1920s when the first soil categorization were enhanced. One of the first to be published was the Public Roads (PR) soil classification system (Huang, 2004). In 1929, the California Highway Department improved a method using the California Bearing Ratio (CBR) strength test (Huang, 2004). The California Bearing Ratio (CBR) method related the material's CBR value to the required thickness to provide protection against subgrade shear failure. The thickness computed was described for the standard crushed stone used in the definition of the CBR test. Several methods based on subgrade shear failure criteria were enhanced after the CBR method. Huang used Terzaghi's bearing capacity formula to calculate pavement thickness, while he applied logarithmic spirals to specify bearing capacity of pavements. Regression equations can also be enhanced using performance data from existing pavements (Huang, 2004). Examples contain the COPES (Darter et al., 1985) and EXPEAR (Hall et al., 1989) systems. Although these models can represent and clarify the effects of specific factors on

[1] Corresponding author: ahmet.unal@erzurum.edu.tr

pavement performance, their limited consideration of materials and construction data result in wide scatter and many uncertainties.

Mechanistic-empirical (M-E) methods represent one step forward from empirical methods. Kerkhoven and Dormon first recommended the use of vertical compressive strain on the top of subgrade as a failure criterion to decrease plastic deformation (Kerkhoven and Dormon, 1953). Saal and Pell published the use of horizontal tensile strain at the bottom of asphalt layer to minimize fatigue cracking. Dormon and Metcalf first used these concepts for pavement design (Saal and Pell, 1960). The Shell Method (Claussen et al., 1977) and the Asphalt Institute Method (Shook et al., 1982; AI, 1992) combined strain-based criteria in their mechanistic-empirical procedures.

In this study, the construction which was completed in 1999 in Erzurum South Ring Road was investigated. Existing superstructure section was examined and this superstructure section are determined that it could be an alternative to the existing superstructure section. Considering that according to the specified conditions in the drainage section of the superstructure design methods of AASHTO-86 was calculated layer thicknesses. The cost calculation was made of existing superstructure section and could be an alternative to the existing superstructure section.

3. Material methods

In this study, the South Ring Road of Erzurum which is built according to AASHTO-86 pavement design method examined. This superstructure layer is determined as will be alternative sections. Erzurum South Ring Road to the top of the existing structure section is given in Table 1. Superstructure section is shown in the Figure 1 used in general.

Table 1
Erzurum South Ring Road existing superstructure section

Type A	
Wearing Course	5 cm
Binder Course	8 cm
Asphalt Base Course	10cm
Road Base Course	20 cm
Plentmix Subbase Course	20 cm
Total Thickness	**63 cm**

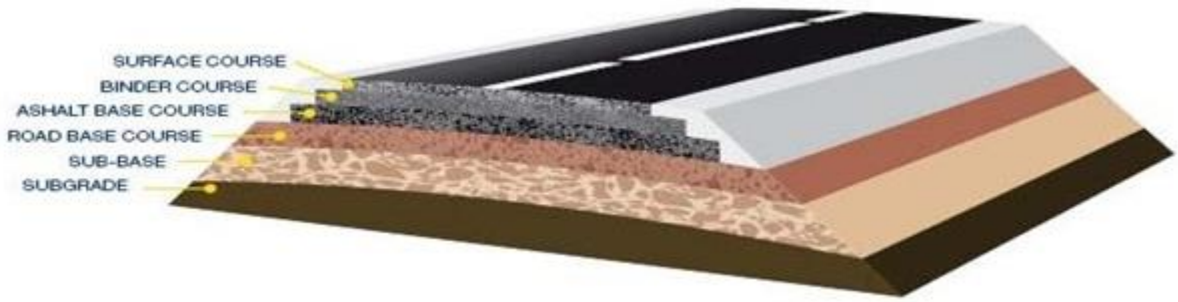


Fig. 1.
Commonly used superstructure section

In the second part of the study alternative superstructure sections were examined and the effects of this on the layer thickness for different superstructure design were investigated. Comparison of selected superstructure sections was calculated according to the AASHTO-86 method and has is given in Equation (2, 3, 4, 5, 6). Undoubtedly, ground bearing capacity values that are used in the calculation show the changing values along the path of a road. The ground bearing capacity value in the calculations was taken as 10.000 psi. The total number of replicates required to drop the end of the service capabilities of the superstructure in the calculation of the different types of pavement sections is defined as $W_{8.2}$=37.178.900 standard axles / project duration.

The design of layers thickness;

Z_r =-1.037, S_0 = 0.45, P_0 = 4.5, P_t= 2.5, M_R = 10.000 psi, has been taken as in calculations.

$$LogW_{8.2} = Z_r \times S_0 + 9{,}36 \times Log(SN+1) - 0{,}20 + \frac{Log\left(\frac{P_0 - P_t}{4{,}2-1{,}5}\right)}{0{,}40 + \frac{1094}{(SN+1)^{5{,}19}}} + 2{,}32 \times Log(M_R) - 8{,}07 \quad (1)$$

where W $_{8,2t}$ is predicted number of 8,2 tones equivalent single axle load applications, Z_r is standard normal deviate, S_0 is combined standard error of the traffic prediction and performance prediction, M_r is resilient modulus, SN is structural number.

Crushed stone subbase M_r value 18.834 psi and the basis of the M_r value is used as plentmix 33.266 psi.

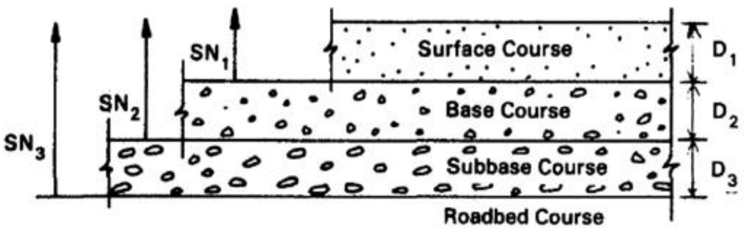


Fig. 2.
Procedure for determining thickness of layers using a layered analysis approach
Source: AASHTO 93 Pavement Structures Design Guide

$$D_1^* \geq \frac{SN_1}{a_1} \quad (2)$$
$$SN_1^* = a_1 D_1^* \geq SN_1 \quad (3)$$
$$D_2^* \geq \frac{SN_2 - SN_1^*}{a_2 m_2} \quad (4)$$
$$SN_1^* + SN_2^* \geq SN_2 \quad (5)$$
$$D_3^* \geq \frac{SN_3 - (SN_1^* + SN_2^*)}{a_3 m_3} \quad (6)$$

SN value is multiplied by the relative coefficients of resistance layer with layer thicknesses (Equation 7).

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3 m_3 \quad (7)$$

where a is the relative strength coefficient, d layer thickness, m refers to the drainage coefficient.
Asphalt concrete wearing course is the layer that is constructed on binder layer and contacts directly to the traffic load. To form a uniform and smooth rolling surface for the wear layer, the flow of the traffic is organized accordingly. Laying uniformly the surface of the bituminous mixture made series of pavers can be ensured. The bituminous binder course on basic or applied as a granular base asphalt. The thickness of the binder course by the amount of traffic varies from 6 to 12 cm.
The most difference between superstructure sections is the base material that is predicted to be used as an alternative material. Crushed stone and fine material consist of a mixture obtained by mixing in a mechanical plant fine material. Subbase layer according to the criteria set out in the specifications laid with pavers is obtained by mixing with water. The fact that the available grounds do not have sufficient transport capacity strength is applied in the circumstances in which the ground should be strengthened. The occurrence of hot mix of living, depending on the underlying floor of asphalt to be applied for the application of plentmix base is a very likely situation. After completion of earthworks disrupted traffic achieved under the platforms. Various distortions occur due to seasonal conditions. Basic material or basic necessaries, making a kind of coating to avoid this situation has necessitated the need. For this reason, stabilizing is performed based application.
Accounts and other alternative body sections with the AASHTO-86 method is used on pavement design is given Table 2.

Table 2
Alternative superstructure sections

Alternative Superstructure Sections					
Type B		**Type C**		**Type D**	
Wearing Course	5 cm	Wearing Course	9 cm	Wearing Course	9 cm
Binder Course	8 cm	Binder Course	12 cm	Binder Course	12 cm
Bituminous Base Course	10 cm	Plentmix Base Course	28 cm	Stabilizing Base Course	60 cm
Plentmix Base Course	20 cm				
Subbase Course	20 cm				
Total Thickness	**63 cm**	**Total Thickness**	**49 cm**	**Total Thickness**	**81 cm**

The unit prices of each layer is taken from the General Directorate of Highways. Unit price list is given in Table 3.

Table 3
The unit prices of the layers

The Unit Price of the Layers	Cost
1 cm thick stuck in 1 m^2 of asphalt concrete base made of hot bituminous	0,405 \$/ m^2
1 cm thick stuck in 1 m^2 of asphalt concrete wearing surface	0,516 \$/ m^2
1 cm thick stuck in 1 m^2 of asphalt concrete binder base	0,430 \$/m^2
To make plentmix base	10,21 \$/ ton
To make with sifted gravel subbase material	2,97 \$/ m^3

Cost accounts for different body types are shown in Table 4. The cost calculation is taken as the road width of 18 meters and road length as 1 km. As a result of the calculations, the cost of superstructure types is calculated.

Table 4
The total price of section types

Section Type	Cost ($/km)
A	132.709
B	85.006
C	119.822
D	102.003

4. Conclusion

Stabilizing the basis of relative strength coefficient is taken as 0,08 in Type D. Relative strength coefficients of the layers in the other superstructure sections as calculated for wearing course 0,44, binder course 0,40, bituminous course 0,36, plentmix course 0,15 and subbase course 0,13.

Layer thicknesses of the alternative superstructure sections is given in Table 2. The main factor of existing different superstructure is used different base materials. Another factor in the calculations of the layer thickness being different is different coefficient of strength of the layer.

Ton price of basic materials have been translated into cubic unit price multiplied by the coefficient of 1,6.

Erzurum South Ring Road of the superstructure section is given in Table 1. As a result of the calculations, the cost of existing pavement section was calculated as 132.709$/km. It was determined that Type B could be as an alternative of Type A. Reasons for the emergence of low cost of the B section is the use of a lower cost material as the base material. Type B superstructure does not have any disadvantages in terms of technique.

When we compared type C with type D, it was calculated that base course of type C must be thicker than type D. This condition is not desirable in terms of technical. When compared in terms of cost, it seems to be making sense of type C.

References

Asphalt-Institute, 1982. *R and Development of the Asphalt Institute's Thickness Design Manual* (MS-1), 9th ed. Research Report 82-2ts, Asphalt Institute, Lexington, KY.

Asphalt-Institute, 1991. *Thickness Design - Asphalt Pavements for Highways and Streets.* Manual Series No.1 (MS-1), Asphalt Institute, Lexington, KY.

Claussen, A.I.M.; Edwards, J.M.; Sommer, P.; Udge, P. 1977. Asphalt Pavement Design - The Shell Method. In *Proceedings of the 4th International Conference on the Structural Design of Asphalt Pavements*, 39-74. Available from Internet: <http://www.pavementinteractive.org/article/1993-aashto-flexible-pavement-structural-design/>.

Huang, Y.H. 2004. Pavement Analysis and Design, *Prentice-Hall*, Upper Saddle River, NJ.

Flexible Pavement Design Guide, 2008. Highways General Manager, Ankara.

Kok, E. 2008. *Design of Highway and Airport Pavements, Differences and Applications in Turkey*. Istanbul Technical University Master Degree Thesis, 3 p.

Pavement Interactive, 2008. *1993 AASHTO Flexible Pavement Structural Design*, Washington D.C.

Saltan, M.; Tıgdemir, M.; Karasahin, M. 2002. Artificial Neural Network Application for Flexible Pavement Thickness Modeling, *Turkish Journal of Engineering, Environment and Science*, 26: 243-248.

Shook, J.F.; Finn, F.N.; Witczak, M.W.; Monismith, C.L. 1982. Thickness Design of Asphalt Pavements - The Asphalt Institute Method. In *Proceedings of the 5th International Conference on the Structural Design of Asphalt Pavements*, 17-44.

EFFECTS OF THE PEDESTRIAN PAVEMENT NETWORK AND ILLUMINATION ON ACCESSIBILITY ON PUBLIC PARKS IN SOUTH AFRICAN CITIES

Dillip Kumar Das[1], James Honiball[2]
[1,2] *Department of Civil Engineering, Central University of Technology, Free State, 20 President Street, Bloemfontein, South Africa, 9300*

Abstract: Public parks are integral elements of residential areas of cities. It is well established that public parks have a positive influence on the social and physical health of the people who have access to them. The public parks despite being seemingly planned according to urban planning guidelines and are located appropriately in the neighbourhoods of the cities of South Africa, they are observed to be highly underutilised. Many social and physical factors that include location, accessibility, crime or fear of crime, life style, and lack of time are generally attributed for such a scenario. However, explicit studies on the factors that influence- and their relationships with the use of public parks by people, particularly in the residential areas of cities are limited. Therore, the objective of this study is to explore how pedestian movement network in the neighbourhoods and illumination levels in the public parks influence the utilization of public parks in the residential areas of South African cities. Blomefontein city of South Africa was taken as a case study, and a survey research method for data collection, subsequent statistical analyses and development of empirical models were follwed. Data were collected through park user survey conducted by using random sampling process, and household survey through startified random sampling by using pre tested questionaires. Besides, physical park utlisation survey was conducted by using continous time lapse digital photography and videograpgy of the public parks. The study revealed that more people use the public parks during evening hours. Higher artificial illumination and availability of quality pedestrian pavement netwoks are the two important factors, which influence public park use, although they do not necessarily influence each other. However, the combination of availability of both factors would enhance the utlisation of public parks significantly.

Keywords: accessibility, illumination, public parks, pavements, road network, residential areas.

1. Introduction

Public parks (PPs) and recreational facilities (RFs) offer people the opportunities for a wide range of leisure, sport and recreational activities. They are crucial for the social and economic health of the cities and towns (Sallis, Frank, Saelens, & Kraft, 2004). It is observed that the habitation areas including residential areas of South Africa in general and in the cities in particular have been going through transformations since the establishment of its new constitution in the year 1994. In the process transformations in urban functions and consequent land uses are observed in many cities of the country. Consequently a hierarchical change in the pattern of residential areas in urban areas has been experienced (Spocter, 2004). For instance, the residential areas have been expanded to develop suburban areas. The suburban areas, which were essentially started for residential purposes, gradually incorporated other urban functions such as commercial, civic and recreational activities. Besides, a stress was laid upon to create organized open spaces including public parks and open recreational facilities in the residential areas of the cities. They become one of the core land uses in the city development plan offering urban social and recreational functions. Although, a number of such public parks and recreational facilities have been developed in most of the South African cities, it is observed that except a few major and organized ones, majority of the public parks in residential areas scarcely utilized. The reason of underutilization these public parks are attributed to many factors that includes lack of amenities, inappropriate location, lack of attractiveness, lack of accessibility, behavioural issues like lack of time and life style, social issues like crime or fear of crime to name a few. However, accessibility to public parks particularly in sub urban residential areas is a crucial challenge. Therefore, the objective of the of study is to explore how two imporatnt accessibility parameters such as illumination levels in the public parks and pedestraian network facilitiess (with respect to road network facilities) influence the accessibility and consequent utilisation of public parks in the residential areas of South African cities. However, other social, cultural, and other physical, visual and symbolic accessibility factors have been kept out of the scope of the paper as they also warrant specific investigation.

The study was conducted by using Bloemfontein city of South Africa as a case study. A survey research method and empirical modelling were used for the purpose. Two hypotheses that (1) availability of improved level of artificial illumination in the public parks; and (2) complete pedestrian facilities along the road networks in residential areas of cities, will improve the utilisation of public parks" are tested. Findings suggest that majority of the people use the parks during evening hours. Artificial illumination is one of the most important factors that influences accessibility of the public parks, and utilisation of the public parks increases with higher level of artificial illumination. Besides, it is also found that more complete the pedestrain facilitiy network along the roads leading to public parks, higher is the urtilisation of the parks.

[1] Corresponding author: ddas@cut.ac.za

2. Literature review

2.1. Role and indicators of success of public parks

Public parks have crucial roles to play in cities. Some of the important roles they play are that they offer open recreational facilities to people, bring people together, increases social bonding, make intergenerational interaction, develop contact with nature (especially if it is natural green spaces), compliment the architectural articulation of the surrounding built areas, improve the value and desirability of the surrounding residential areas, and create an area for people to orientate themselves with the greater part of the city or town (Dempsey, 2012). Public parks have many design aspects, which positively contribute to the well-being and value of the surrounding spaces. Properly planned and designed open green spaces (OGSs) and public parks greatly add to the aesthetic quality of the surrounding areas and satisfaction inhabitants around them. Also, they create a restorative environment, which cannot be neglected as they positively influence the inhabitant's well-being and health (Ariane, Bedimo-Rung, Andrew, Mowen, Deborah, Cohen, 2005).

The project for public spaces (PPS, 2011) evaluated thousands of public spaces around the world and has found that successful public parks and recreational facilities have four key qualities. Firstly, they are accessible; secondly, people are engaged in activities there; thirdly, the space is comfortable and has a good image; and lastly, it is a sociable place where people meet each other and take people with them when they come to visit (PPS, 2011). Based on such studies, a tool called "The Place Diagram (Figure 1)" was developed to aid people to judge whether any public place is good or bad. One of the important aspects, which have been emphasized in it is the access and linkages of parks and recreational facilities, which essentially influence the success of the public parks and open recreational areas PPS, 2011).

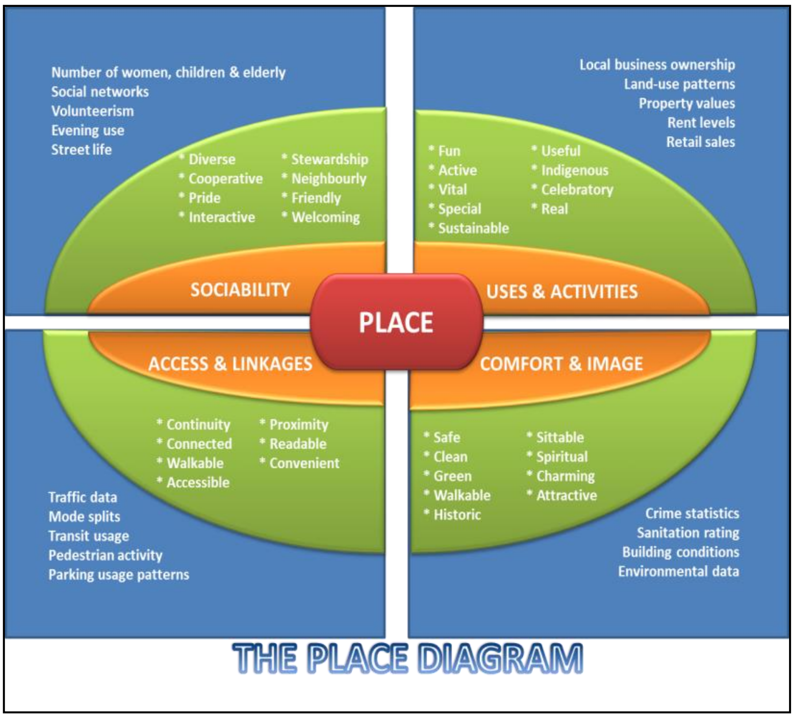


Fig. 1.
The Place diagram for public parks
Source: Project for Public Spaces (2011)

2.2. Forms of accessibility to public parks

The accessibility of public parks is related to the ability of people to reach the space by means of public transport, private transport or pedestrian infrastructures. Accessibility is often considered as a crucial factor to make a public park function as purposed. For instance, a public park that is set on a busy road may draw more people that are passing by as well as people using services and facilities that are nearby (Dempsey, 2012). Although, there is no unanimity on the definition of accessibility of public parks because of the various roles it plays and its effect on the vibrancy and usefulness of public parks, it can be categorized into three forms such as, physical access, visual access, and symbolic access (Sendi and Golicˇnik Marusˇic, 2012).

2.2.1. Physical access

Physical access to public parks requires the space to have proper linkage from neigbouring spaces as well as no barriers preventing pedestrians to enter the space. According to Sendi and Golicˇnik Marusˇic, (2012) physical access to public parks should be easy for children and elderly people to make use of. Houses and residential areas next to the public parks should also have relatively easy access to the space. Physical access is hampered by vehicular movements around the public parks. Also, the type, quality and continuity of the pavements of the pedestrian facilities are factors that encourage or discourage people to visit the parks at the neighbourhood or residential area level (Dell'Acqua, Mario, Russo, 2012; Žilionienė, Mario, Russo, 2013). The physical accessibility of parks is also influenced by the density of the neighbourhood which surrounds it, and perhaps by the shape of the park. Besides, convenient access for physically challenged people is an essential element of the physical access of the public parks (Dempsey, 2012).

2.2.2. Visual access

The visual access of a public park refers to the visual connection a user would have with the park they are heading towards. Visual access contributes to the safety of the user due to the proper visibility needed to safely navigate to the park. Not only must a public park be easily visible to its users, it must also ensure that the users are visible when accessing as well as when using the parks (Sendi and Golicˇnik Marusˇic, 2012). According to Peña-García, Hurtado, & Aguilar-Luzón, (2015), artificial illumination of a public park is a key element in making sure that the visual access of a public park is adequate.

2.2.3. Symbolic access

Symbolic access to public parks is becoming more and more important in defining the full accessibility and vibrancy of the public parks. Symbolic access can be defined by the level and quality of signs and marks that share information to prospective users on who or what is welcome and who or what is not in the areas and territories of the space. These markings and signs can also be elements like structures, landmarks, monuments, sculptures, etc. Public display areas and programs, such as, pavilions, galleries, and other theme objects can also be seen as features contributing to symbolic access. Users such as groups (teenagers, small children, dog walkers, etc.), maintenance workers, and security staff visible in the public parks are also contributors to the symbolic access of the public parks (Sendi and Golicˇnik Marusˇic, 2012).

2.3. Issues of accessibility and use of public parks

The issue of accessibility to the public parks is becoming more and more debated with regards to sustainable urban planning. Accessibility to the public parks is essential for the health, well-being and cultural equality of the societies. This awareness can mainly be attributed to the awareness about the health and well-being benefits that are gained from the successful use of the public parks (Thomson, Aspinall, & Roe, 2014). Access to the public parks is particularly useful to children, lower socioeconomic group, and people with physical/mental disabilities (La Rosa, 2014).

Challenges of accessibility to public parks vary according to the different access needs people. If accessibility to the public parks is considered as the degree of ease at which a user can reach their destination, then fully determining the factors and variables affecting the accessibility of public parks should be a pre- requisite for further analysis on planning for vibrant and sufficient public parks (La Rosa, 2014; Sendi and Golicˇnik Marusˇic, 2012).

In addition to the spatial accessibility of public parks, Weiss et al., (2011) suggests that there are many other variables of the environment that might negatively affect the use and accessibility of the public parks. In this regard, the research conducted in the perspective of environmental justice highlights the linkage between the inequalities in the spatial distribution of public parks and natural hazards in the environment. For example communities with less or limited accessibility to public parks face exposure to environmental ailments such as air pollutions (Evcil, 2012). Besides, it is also found that fear of crime or concerns for personal safety limits the accessibility of the parks as it discourages the users to make use of the available modes of access to the public parks. For instance, these fears and concerns may lead users to rather seek out other recreational facilities, which are perceived to be safer to access (Weiss et al., 2011). However, Painter (1996) observed that adequate levels of illumination in public parks are often a deterrent for crime and inadequate levels of illumination in the parks are often a deterrent for potential users of the parks.

Evidence from the literature suggests that most of the researches on the accessibility to public parks that have been carried out until now are mostly on industrialized nations, which have well-established infrastructure. However, on the contrary very little is known about accessibility of public parks, particularly the influence of illumination level in the parks and availability of pedestrian facility network on the park use, in fast growing cities of developing countries (Wright, Zarger, & Mihelcic, 2012). Therefore, an effort has been made in this study to understand the relationship between illumination and pedestrian facility network leading to the parks and the use of public parks in a city of a developing country.

3. Study Area

Bloemfontein city of South Africa is used as a case study for this investigation. It is comprised of 35 suburban residential areas. The city has an adequate number of hierarchical public parks and recreational facilities, which includes central park and stadiums at the city level, public parks at the neighbourhood level and residential area level. However, most of the parks in the residential areas are observed to be lacking in vibrancy and more so found to be underutilized. Accessibility, perception of safety, actual safety, lack of entertainment amenities, lack of maintenance, and lack of comfort are some of the suggested factors, which discourage the higher use of these parks. Therefore, it was felt relevant to explore the relevant accessibility factors such as illumination and pedestrian facilities that influence the utilisation of the public parks in the city.

4. Research methodology

The investigation followed a survey research methodology and development of empirical models. Data was collected through household survey and physical and park use surveys. The surveys were conducted in four representative suburbs of the city such as Universitas (South-Western part of Bloemfontein), Langenhovenpark (Western part of Bloemfontein), Batho (Eastern part of Bloemfontein), and Lourier Park (Southern part of Bloemfontein). The suburbs were selected on the basis of a set of selection criteria such as, geographic location, population, social demographic condition, availability of number and type public parks, type of accessibility through road network, and size. These selected suburban residential areas vary from each other in terms of its diverse demographics, size, location, and accessibility via road networks. Household survey with a sample size of 208 was conducted by using systematic stratified random sampling process through semi-structured interviews. Physical and park use survey were conducted by using continuous digital photography and videography. Twenty four public parks located in the four selected residential areas were identified for the physical and park user survey. For this purpose a camera was set up at each of the identified public parks, which filmed the park for 7 days non-stop to monitor the daily use of each parks and various accessibility issues.

Physical accessibility was evaluated based on the availability of pedestrian facilities and road network leading to the parks. Pedestrian facilities include properly maintained paved pathways along the roads without obstructions/barriers/encroachments/gaps. The road network includes the local roads and access streets passing through the residential areas. While analysing the accessibility factors with regards to pedestrian facilities the ratio of length pedestrian facilities to length road network was considered as the relevant parameter for the convenience of analysis as both are dependent on each other. Similarly lighting facilities and their intensity in lux in the evening times was taken as the level of illumination in the parks. The analysis was conducted by use of statistical methods such as correlation, significance tests and trend analysis by developing empirical models.

5. Findings and discussion

Table 1 presents the correlation coefficients between parks use and illumination level, and park use and pedestrian facility network leading to the parks as well as significance test results between park use and accessibility parameters. A correlation between the average number of users and recorded level of illumination was conducted and it is found that illumination level in parks and use of parks are highly correlated (cc=0.84). The high correlation coefficient suggests that higher the illumination levels of the public parks, the higher will be the average number monthly users of the public parks. The high correlation between the average number public parks users per month and the pedestrian facility network to road network ratio (cc=0.82) means that the more complete the pedestrian facility network in the service areas, the higher will be the average number of public parks users per month. Besides, the significance test results show that p values (both single tailed ad two tailed) for each variable are <0.05 for $\alpha <0.05$. This establishes that there are significant relationships exist between the accessibility variables such as pedestrian facility network to road network ratio, and illumination level of parks in evenings with the park uses in Bloemfontein, thus establishing the two hypotheses envisaged that (1) availability of improved level of artificial illumination in the public parks; and (2) complete pedestrian facilities along the road networks in residential areas of cities, will improve the utilisation of public parks.

Table 1
Correlation and significance test results

Accessibility Parameter	**Decadent parameter**	**Correlation coefficient (cc)**	**r^2**	**T value**	**df**	**p***	**p****
Illumination level of parks in the evening	Park use	0.84	0.92	6.82	40	0.0000003	0.0000006
Pedestrian facility network to road network ratio	Park use	0.82	0.92	7.40	32	0.00000001	0.00000002

*Note: *single tailed; ** two tailed p values for α <0.05*

5.1. Influence of the level of illumination in public parks in the evenings on the number of users of public parks in the study area

Figure 2 presents the relationship between the illumination levels in the evenings and the average number of monthly users of the public parks in the study area. The relationship is presented in the equation 1 (Eq.1).

$$Y_1 = 37.585X_1 + 89.75 \tag{1}$$

$r^2 = 0.92$

Y_1 = Number of public park users per month; X_1= Illumination level in parks in lux

The relationship proves that a linear relationship exists between illumination level and number of park uses. It is observed that parks with very low illumination (<3 lux) experience very few visitors and more people use parks where illumination level is high (>10 lux). However, majority of the parks have illumination level less than 20lux recommended by the Encyclopedia of Occupational Health and Safety. Thus, as per the trend analysis the average number of monthly park users increases significantly along with an increase in the level of illumination of the public parks in the evenings. So, significant improvement in the illumination in the public parks during evening is essential to improve the uses of public parks in the study area.

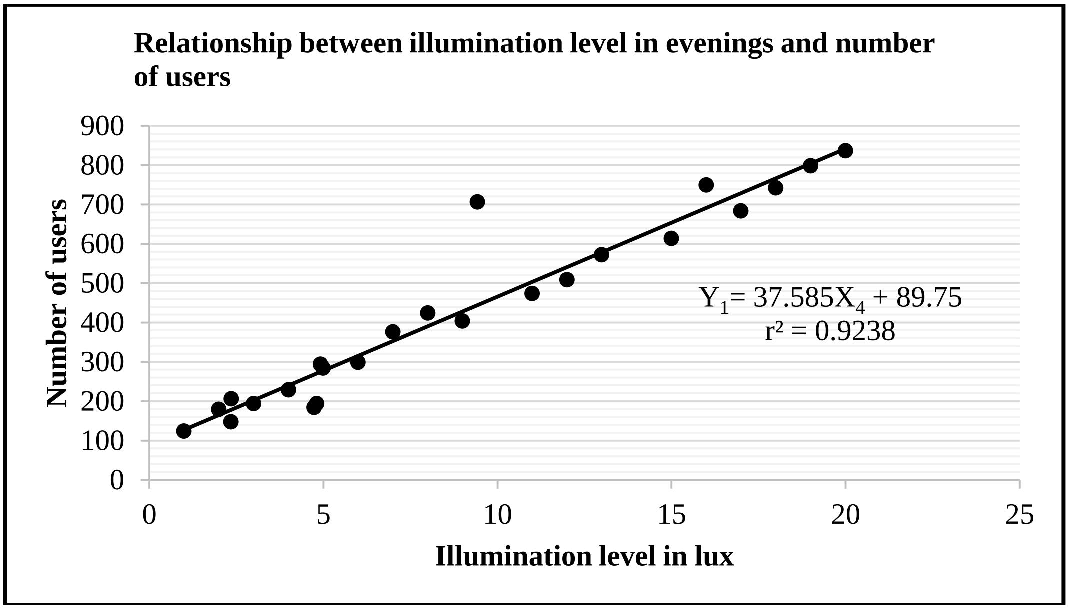


Fig. 2.
Influence of the level of illumination in public parks in the evening on the number of users of public parks

5.2. Influence of pedestrian facility network to road network ratio on the number of users of public parks in the study area

Figure 3 shows the relation between the pedestrian pavement network to road network ratio and the average number monthly users of the public parks in the study area. The relationship is presented in the equation 2 (Eq.2).

$$Y_1 = 2.032e^{5.9542X_1} \tag{2}$$

$r^2 = 0.92$
Y_1 = Number of public park users per month; X_1= Pavement network to road network ratio

The trend analysis from Figure 3 revealed that the average number of monthly users increases gradually (non-linearly) as the pedestrian facility to road network ratio increases up to 0.85; however, it increases exponentially as the ratio improves beyond 0.85. This indicates that if the pedestrian facilities are not available commensurate to the road network, it will act as a barrier for the people to use the parks, however, more number of people use parks where the pedestrian facility network is more complete, i.e., if the pedestrian facilities are almost provided along all the roads leading to the parks without much obstructions.

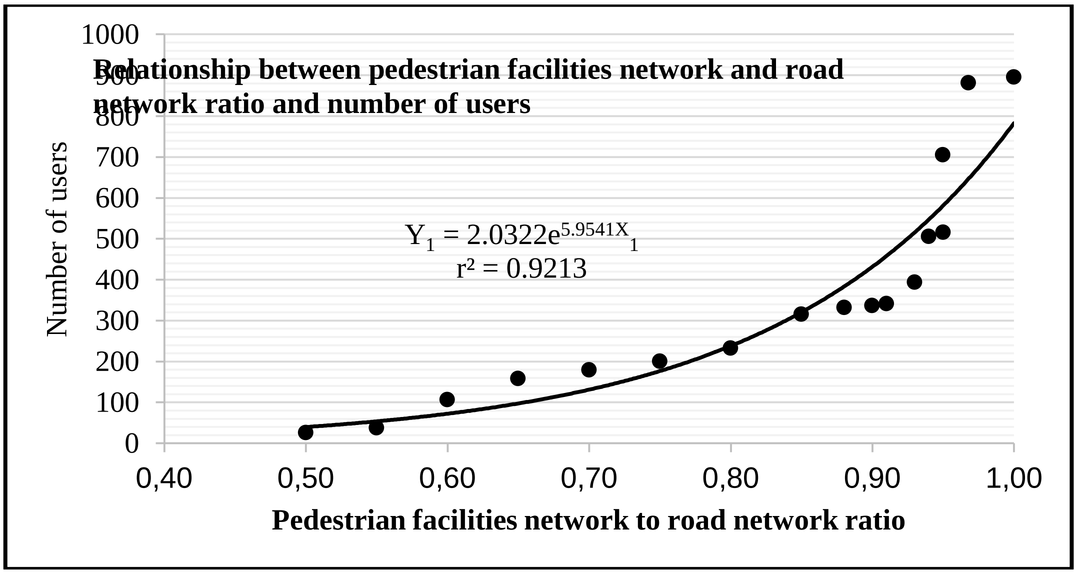


Fig. 3.
Influence of pedestrian facilities network to road network ratio on the number of users of public parks

6. Conclusion and further research

Accessibility of public parks in residential areas in the South Africa cities is a challenge. This study revealed that illumination and pedestrian facility network along the roads leading to the public parks are two major parameters, which influence the accessibility and consequent use of the parks. The relationship between the illumination and use of parks, and pedestrian facility network and use of public parks, are established by empirical models as well as by significance tests. It is found that number of users of the public pars increases with the increase in illumination and pedestrian facility. However, there are various other factors, such as physical access, social and cultural issues, which also influence use of public parks, which is the further scope of the research. Nevertheless, at its current state, it is revealed that there is a need to improve the artificial lighting infrastructure in the public parks and to make provision for complete pedestrian facilities along the roads leading to the public parks in residential of Bloemfontein city in order to improve their use.

References

Ariane, L.; Bedimo-Rung.; Mowen, A.J.; Cohen, M.D.A. 2005. The Significance of Parks to Physical Activity, *American Journal of Preventive Medicine*, 2(2S2): 159-168. doi:10.1016/j.ampre.2004.10.024.

Dell'Acqua, G.; De Luca, M.; Russo, F. 2012. Procedure for Making Paving Decisions with Cluster and Multicriteria Analysis, *Transportation Research Record,* 2282: 57-66.

Dempsey, N. 2012. Neighbourhood Design: Green Space and Parks, *International Encyclopedia of Housing and Home,* 5:12-20. doi:10.1016/B978-0-08-047163-1.00540-3.

Evcil, A.N. 2012. Raising Awareness about Accessibility, *Procedia - Social and Behavioral Sciences*, 47: 490–494. doi:10.1016/j.sbspro.2012.06.686.

La Rosa, D. 2014. Accessibility to greenspaces: GIS based indicators for sustainable planning in a dense urban context', *Ecological Indicators*, 42: 122-134. doi:10.1016/j.ecolind.2013.11.011.

Painter, K. 1996. The influence of street lighting improvements on crime, fear and pedestrian street use, after dark, landscape and urban planning, 35(2-3): 193-201.

Peña-García, H.; Aguilar-Luzón, M.C. 2015. Impact of public lighting on pedestrians' perception of safety and well-being, *Safety Science*, 78: 142–148. doi:10.1016/j.ssci.2015.04.009

Project for Public Spaces (PPS). 2011. No Title. *What Makes a Successful Place?* Retrieved September 18, 2013, from https://www.pps.org/reference/grplacefeat

Sendi, R.; Golicˇnik Marusˇic, B. 2012. Neighbourhood Design, *Public Spaces*, pp.21-28. doi:10.1016/B978-0-08-047163-1.00541-5.

Sallis, J.F.; Frank, L.D.; Saelens, B.E.; Kraft, M.K. 2004. Active transportation and physical activity: opportunities for collaboration on transportation and public health research, *Transportation Research Part A: Policy and Practice*, *38*(4):249-268. doi:10.1016/j.tra.2003.11.003.

Spocter, M. 2004. A macro analysis and GIS application of urban public space closures in Cape Town, 1975-2004, pp. 90-113.

Thompson, C.W.; Aspinall, P.; Roe, J. 2014. Access to Green Space in Disadvantaged Urban Communities: Evidence of Salutogenic Effects Based on Biomarker and Self-report Measures of Wellbeing, *Procedia - Social and Behavioral Sciences*, 153: 10-22. doi:10.1016/j.sbspro.2014.10.036.

Weiss, C.C.; Purciel, M.; Bader, M.; Quinn, J.W.; Lovasi, G.; Neckerman, K.M.; Rundle, A.G. 2011. Reconsidering access: park facilities and neighborhood disamenities in New York City, *Journal of urban health: bulletin of the New York Academy of Medicine*, 88(2): 297-310. doi:10.1007/s11524-011-9551-z.

Wright Wendel, H.E.; Zarger, R.K.; Mihelcic, J.R. 2012. Accessibility and usability: Green space preferences, perceptions, and barriers in a rapidly urbanizing city in Latin America, *Landscape and Urban Planning*, 107(3): 272-282. doi:10.1016/j.landurbplan.2012.06.003.

Žilionienė, D.; De Luca, M.; Francesca, R. 2013. Evaluation of Climatic Factors Based on the Mechanistic-Empirical Pavement Design Guide, *The Baltic Journal of Road and Bridge Engineering*, 8(3): 158-165.

MODELING OPERATING SPEED USING ARTIFICIAL COMPUTATIONAL INTELLIGENCE ON LOW-VOLUME ROADS

Mario De Luca[1], Francesco Abbondati[2], Francesco Saverio Capaldo[3], Salvatore Antonio Biancardo[4], Daiva Žilionienė[5]
[1,2,3,4] Department of Civil, Architectural and Environmental Engineering (DICEA), University of NaplesFederico II, Italy
[5] Department of Roads, Vilnius Gediminas Technical University, Lithuania

Abstract: In recent years, Artificial-Computational Intelligence (ACI) have found increasing applications in management of transportation infrastructures. Examples of ACI applications can be found in highway management however, compared to transportation planning, research of ACI methods applied to infrastructure management has been relatively limited. In this study was used artificial intelligence ANN (Artificial Neural Network). In particular the objective of the research study is to compare the predicted operating speed on tangents and circular curves for low-volume roads by using two different statistical approaches.The starting point was to predict the operating speed on investigated tangents and circular curves elements by using four regression equations developed using a traditional ordinary–least-squares method (OLS) as shown in a previous work of the authors. Then, the same database was used to calibrate new operating speed models by using ANN procedure. The results have shown that ANN models offer more reliable results in terms of predicted operating speed than those returned by OLS method on all circular curves and on tangents lengths greater than 500m. For tangents length less than 500 m, OLS method is to be preferred to ANN procedure.

Keywords: artificial-computational intelligence, data mining, artificial neural network, operating speed, multivariate regression.

1. Introduction

In recent years, Artificial-Computational Intelligence (ACI) have found increasing applications in management of transportation infrastructures. Many researchers, in particular, have employed Artificial Neural Network (ANN) procedures to analyze factors related to data processing. In the scientific literature, many research works have dealt with the road safety issues, driver speed behavior, traffic flow. The comparison of results coming from ordinary simulation method and ANN procedure is often carried on.

Satish et al. (2007) estimated the annual average daily traffic (AADT) for low-volume roads. Artificial neural networks are compared with the traditional factor approach for estimating AADT from short-period traffic counts. The neural network approach can be particularly suitable for estimating AADT from two 48-h counts taken at different times during the counting season. In fact, the 95th percentile error values of about 25 percent as obtained in this study for the neural network models compare favorably with the values reported in the literature for low-volume roads using the traditional factor approach.

Faghri and Aneja (1996) proposed and examined alternative methodology for trip prediction by using artificial neural network (ANN) concepts and techniques. The data base used was made available by the Delaware Department of Transportation. The data were collected for 60 sites throughout Delaware between 1970 and 1974 and are based on field counts and home interviews. Twenty-six regression models were calibrated on these data. In addition, 18 ANN architectures were developed, and their predictions were compared with those from regression models. Comparisons indicate that the ANNs have the capability to represent the relationship between the trip production rate and the independent variables more accurately than regression analysis at no additional cost of increasing the data base.

Saito and Fan (1999) analyzed the effects of architecture, learning mode, and learning rate on the performance of a level-of-service (LOS) analysis model by using an artificial neural network (ANN). Multilayer LOSANN models demonstrated improved quality of learning and testing over single layered models in evaluating level of service of signalized intersections given geometric, traffic, and traffic signal control data.

Hassan and Mohamed (2007) focused on accident location with respect to the plaza structure (before, at, after plaza) and driver injury severity (no injury, possible, evident, severe injuries). Two well-known artificial neural network (ANN) paradigms were investigated: the Multi-Layer Perceptron and Radial Basis Functions neural networks. The performance of ANN was compared with calibrated logit models. Modeling results showed that vehicles equipped with ETC devices, especially medium/heavy-duty trucks, have higher risk of being involved in accidents at the toll plaza structure.

Mohammadian et al. (2007) used the nested logit model and the multilayer perceptron artificial neural network to investigate the household vehicle choice problem in terms of their applicability. Both methods generated strong results, although the multilayer perceptron artificial neural network yielded better predictive potential.

Douglas et. al (2007) used speed profile models as a diagnostic tool for highway engineers. Previous work investigated relationships between operating speed and geometric roadway elements for permanent roadway conditions on predominantly two-lane rural roads. However, little research of this type has been directed specifically toward construction work zones. In this study, a speed profile model for construction work zones on high speed highways was developed using artificial neural networks. The model inputs include horizontal and vertical alignment variables, cross section dimensions and traffic control features. A linear reference system is used for model input and output. Three categories of vehicles-cars, trucks, and all vehicles-were used in this study. Models for the 15th percentile speed, mean

[2] Corresponding author: francesco.abbondati@unina.it

speed, and 85th percentile speedwere developed.
Ismail (2010) developed methods for obtaining maps to determine traffic Hot Spots in Konya, Turkey, by applying linear analysis supported by a Geographical Information Systems (GIS). In this research, a GIS system was used to organize geometry, traffic, environmental conditions and accident data. Subsequently, the data contained in the GIS were processed using two different techniques of analysis: "non-linear multiple regression" and "artificial neural networks". In particular, the second technique, used in this field for about 10 years, is gaining growing consensus for the construction of predictive accident models.
Abdel-Aty and Abdelwahab (2002) investigated the use of two well-known artificial neural network (ANN) paradigms: the multilayer perceptron (MLP) and fuzzy adaptive resonance theory (ART) neural networks for analyzing the severity of driver injury. The objective of this study was to investigate the viability and potential benefits of using ANN to predict driver injury severity if a crash occurs. ANN performance was compared with a calibrated ordered probit model. Modeling results showed that testing classification accuracy was 73.5% for MLP, 70.6% for fuzzy ARTMAP, and 61.7% for the ordered probit model. This result indicates more accurate injury severity prediction capability for the ANN (particularly MLP) compared with other traditional methods.
This study is part of a wide research program (Capaldo, 2004a; Capaldo, 2004b; Dell'Acqua and Russo, 2010). In particular is a continuation of a research project (Dell'Acqua and Russo, 2011) that developed four operating speed prediction models for horizontal curves and tangents on low-volume roads: a) 2 models on tangents were associated with the segment length (the first one can be applied on the tangents with a length of less than 500 meters and the second one on tangents with a length greater than 500 meters); b) 2 models on the circular elements were associated to a mean CCR (Curvature Change Rate) value of the roadway segment to which the curve belonged (the first one can be applied on the curves with a CCR value of less than 240grad/km and the second one with a CCR value greater than 240 grad/km). The objective of this research is to compare the predicted operating speed on tangents and circular curves for low-volume roads by using two different statistical approaches: Artificial Neural Network (ANN) versus Least-Square Model (OLS).

2. Operating speed prediction models by least-square model (OLS) method

Four prediction models were developed by the authors in a previous work (Dell'Acqua and Russo, 2011) for the analyzed roadways: two models on tangents and two models on the circular curves. Speed observations on the circular curves with a radius greater than 500 meters were included in the same database of tangents because drivers' behavior is very similar to that adopted on the tangent segments. The models were created using the statistics software. All parameters included in the models are significant with a 95% confidence level. The best specification of the ordinary - least-square model (OLS) of operating speeds on tangents, in kilometers per hour, with a length greater than 500 meters is as follows with adjusted coefficient of determination (ρ^2) of the model equal to 0.83:

$$V_{85T} = 79.67 + 2.8 \cdot 10^{-3} \cdot L + 0.011 \cdot R_{PC}^{3/2} - 0.23 \cdot R_{PC} + 0.15 \cdot V_{85PC} - 2.40 \cdot INT - 4.94 \cdot PD \tag{1}$$

The best specification of the OLS model for operating speeds on the tangents with a length of less than 500 meters, in kilometers per hour, is as follows with adjusted coefficient for the determination (ρ2) equal to 0.89:

$$V_{85T} = 61.56 + 2.4 \cdot 10^{-4} \cdot R_{PC}^2 - 0.11 \cdot R_{PC} + 0.017 \cdot D - 3.29 \cdot INT + 0.30 \cdot V_{85PC} - 3.41 \cdot PD \tag{2}$$

The best specification of the OLS model for operating speeds on horizontal curves with a mean CCR value of less than 240grad/km, in kilometers per hour, is as follows with adjusted coefficient for the determination (ρ^2) equal to 0.81:

$$V_{85C} = 55.74 + 5.57 \cdot W - 0.038 \cdot CCR_S + 10^{-5} \cdot CCR_S^{\,2} - 0.03 \cdot L - 0.48 \cdot RES - 4.65 \cdot INT + 7.3 \cdot 10^{-4} \cdot L_{PT} - 0.064 \cdot CCR - 0.30 \cdot PD \tag{3}$$

The best specification of the OLS model for operating speeds on horizontal curves with a mean CCR value greater than 240 grad/km, in kilometers per hour, is as follows with adjusted coefficient for the determination (ρ2) equal to 0.72:

$$V_{85C} = 59.16 + 0.20 \cdot W^2 - 0.023 \cdot CCR_S + 10^{-5} \cdot CCR_S^{\,2} - 0.69 \cdot RES + 8.8 \cdot 10^{-2} \cdot R_{PC} - 3.5 \cdot 10^{-4} \cdot R^2{}_{PC} - 2.63 \cdot PD \tag{4}$$

where:

- V_{85T} = predicted operating speed value on tangent segment (km/h);
- L= total tangent length (m);
- RPC= radius of the preceding curve (m);
- V_{85PC}= operating speed in the middle section of the preceding curve (km/h);
- INT= intersection indicator, which is equal to 1 if the intersection is located 150 m before or after the surveyed location and 0 otherwise;
- PD= pavement distress indicator, which is equal to 0 if pavement distress is absent, which means that the pavement condition does not influence the driver free-speed behavior, and which is greater than 0 if the level of pavement distress is not low and this condition negatively influences the driver speed behavior, causing a speed decrease (1 if the distress is low, 2 if the distress is high, and 3 if the distress is very high);
- D= distance from the survey point from the end section of the preceding horizontal curve (in meters);
- V_{85C}= predicted operating speed on horizontal circular curve (km/h);
- W= width of travel lanes plus shoulders (m);
- RES= number of residential driveways per kilometer;
- LPT= length of preceding tangent (m).

3. Techniques used in data analysis

3.1. The ANN (Artificial Neural Network) multilayer approach

Inspiration for the structure of the ANN is taken from the structure and operating principles of the human brain. It is made up of neurons linked by connections that represent the connections between the biological synoptic neurons. The function of a biological neuron is to add its input and produce an output. This output is transmitted to subsequent neurons, through the synoptic joints, only if the transmitted signal is high (i.e., greater than a predetermined value), otherwise, the signal is not transmitted to the next neuron. In the network, therefore, a neuron calculates the weighted sum, by using Equ.5 (considering the input xi and weights wi) and compares it with a threshold value; if the sum is greater than the "threshold" value, the neuron "lights up" and the signal is transmitted. Otherwise, the neuron does not turn on and the flow stops.

$$I = \sum_{i=1}^{n} w_i \cdot x_i \tag{5}$$

The activation value "u_i" rather than "u_j", connected to weight W_{ij}, is a function of the weighted sum of the input. This function may take various forms. In this study, a function of type Equ.6 was used.

$$u_j = \frac{1}{1+e^{-(\Sigma(i) w_{ij} uj + \vartheta j)}} \tag{6}$$

where θ_j is the bias unit u_j (i.e. the degree of sensitivity of u_j when it receives an input signal from u_i).

3.2. Multi Layer Perceptron (MLP) and the Back Propagation (BP) algorithm

In this study, a neural network with MLP architecture was used. Training was carried out using the Back Propagation (BP) algorithm. The neurons (or units) that comprise this type of network are organized into layers: an input layer, an output and a number of intermediate layers between input and output referred to as hidden, defined by the user. Initially the weights are assigned random values normalized in the range [0,1] or [-0.5, +0.5] and initially there is a pattern "p" input to the network: Xp = (X0, X1, X2, ..., Xn-1) with X0 = 1 and a vector consisting of the output values Tp = (T0, T1, T2, ..., Tm-1). In this way, the network will consist of (n-1) input neurons and (m-1) output neurons. The "weighted sum of the inputs" for each layer is calculated using equation 5, and its value of activation, i.e. output, using equation 6. Then, the weights must be changed so that the output of the network (i.e. the output of the last layer of neurons) increasingly approximates the target set by the user. We defined a function error Equ.7 proportional to the square of the difference between the output and target for all output neurons:

$$E_p = \frac{1}{2}\sum_j (T_{pj} - O_{pj})^2 \tag{7}$$

Subsequently, Back Propagation is applied i.e. the weights are varied so that error Ep tends towards zero (starting from the last layer to the first). We define, for the current pattern p, a variation Δw_{ij} of weight w_{ij} between the neuron i and j that given by Equ.8.

$$\Delta_p w_{ij} = -\alpha \frac{\partial E_p}{\partial w_{ij}} + \beta \Delta_{p-1} w_{ij} \tag{8}$$

where α is the learning coefficient (learning rate), β is momentum, and Δp-1wij is the variation of the same weight calculated according to the previous model. The new weights are given by Equ.9.

$$w_{ij}{}^{new} = w_{ij}{}^{old} + \Delta_p w_{ij} \tag{9}$$

The variation of the weights is calculated starting from the layer of output neurons and backward toward the first hidden layer. The derivatives can be calculated using equations 10.

$$\Delta_p w \ = \alpha A_i \delta_j + \beta \Delta_{p-1} w_{ij} \tag{10}$$

where Ai is the value of the i-th neuron of the layer being considered; δj is given by Equ.11 if we are considering the output layer.

$$\delta_j = (T_j - O_j) O_j (1 - O_j) \tag{11}$$

It is given by Eq.12 for all other intermediate layers.

$$\delta_j = I_j (1 - I_j) \sum_k w_{jk} \delta_k \tag{12}$$

To train a network, this process must be run many times (at least 1,000) with different patterns, each of which features a different weight. This process is performed until the error is less than a predetermined value (the value is set by the user). When the process converges, the network is ready to classify a new input with an unknown target. The parameters α and β are chosen by the user with values between 0 and 1; in the present study α was assumed equal to 0.5 and β equal to 0.4. In particular, α is linked to the convergence of the network.

4. Data collection

The collection of speed data was carried out in 2009 on dry roads and during daylight hours. The measurements were conducted by using a light detection and ranging KV laser (LIDAR gun). The analyzed roadways fall within the Salerno Province network (southern Italy): low-volume roads SP 30, SP 52, SP 312, SP 135, SP 262, SS 166, SS 103, and SS 426, located partly in the region of Piana del Sele and partly in the region of Vallo di Diano. The parameters (Discetti et al., 2011; Esposito et al., 2011) observed for each roadway section are speed values, roadway features [width of the lane, radius of the horizontal curve, the curvature change rate (CCR) of the homogeneous segment, CCR of a single circular curve (CCRS), and tangent and curve lengths], the presence of intersections, the number of residential driveways per kilometer, and pavement distress. The geometric elements used to study driver speed behavior (Dell'Acqua et al., 2013c; Esposito et al., 2012) included 80 tangent segments, 40 circular elements, and 70 tangent–curve–tangent transitions to study deceleration and acceleration actions.

5. Results and discussion: ANN applications

5.1. ANN application

ANN models (See Figure 1 and Table 1) were obtained by using Artificial Neural Network technique shown in the previous section. The variables in ANN models are shown in Table 2 and only 70% of whole database was used in the calibration phase and the remaining data for verification. Different configurations were considered for the architecture of the neural network. The best architecture of ANN network is shown for each model in Figure 1. Moreover, Table 1 shows ANN.

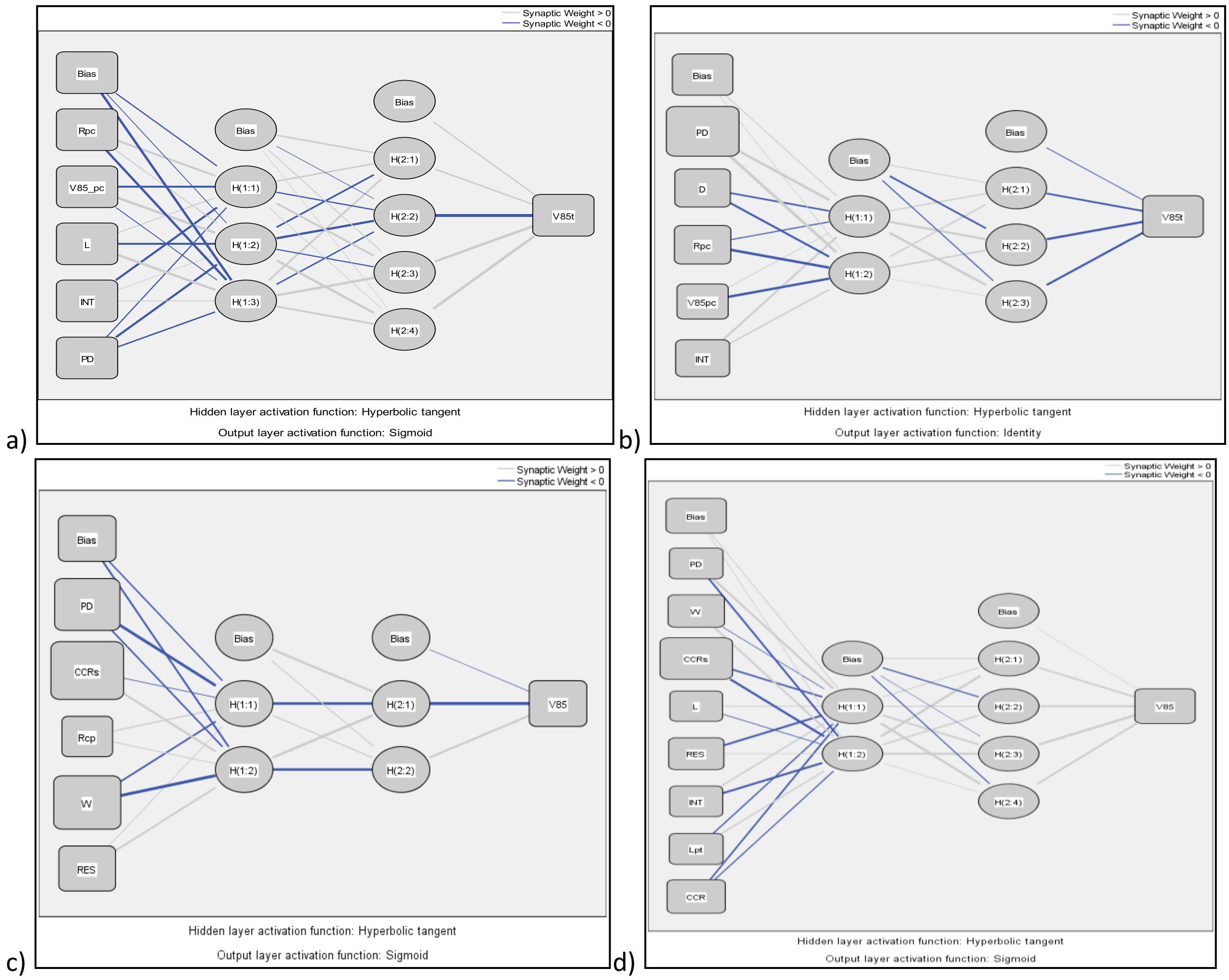


Fig. 1.
ANN architecture for each model
a) Tangent Model 1 (L>500m); b) Tangent Model 2 (L<500m); c) Curve Model 3 (CCR>240 grad/km); d) Curve Model 4 (CCR<240 grad/km)

Table 1
Parameter estimates for each model

Model 1 (L>500m)									
Predictor		Predicted							
		HiddenLayer 1			HiddenLayer 2				Output Layer
		H(1:1)	H(1:2)	H(1:3)	H(2:1)	H(2:2)	H(2:3)	H(2:4)	V_{85t}
Input Layer	(Bias)	-.255	-.099	-.718					
	R_{pc}	.581	.178	-.686					
	V_{85_pc}	-.455	.908	-.155					
	L	.182	-.362	.758					
	INT	-.508	.077	.126					
	PD	-.187	-.551	-.304					
HiddenLayer 1	(Bias)				.335	-.057	.163	.042	
	H(1:1)				.334	-.274	.494	.088	
	H(1:2)				-.340	-.743	-.238	.745	
	H(1:3)				.438	-.291	.788	.458	
HiddenLayer 2	(Bias)								.282
	H(2:1)								.325
	H(2:2)								-1.031
	H(2:3)								.938
	H(2:4)								1.193
Model 2 (L<500m)									
Predictor		Predicted							
		HiddenLayer 1			HiddenLayer 2				Output Layer
		H(1:1)	H(1:2)		H(2:1)	H(2:2)	H(2:3)		V_{85t}
Input Layer	(Bias)	.170	.053						
	PD	1.074	1.745						
	D	-.392	-.543						
	Rpc	-.285	-1.254						
	V_{85pc}	.155	-1.067						
	INT	.490	.374						
HiddenLayer 1	(Bias)				.247	-.401	-.278		
	H(1:1)				.286	.633	.691		
	H(1:2)				.309	.381	.012		
HiddenLayer 2	(Bias)								-.161
	H(2:1)								-.449
	H(2:2)								-.662
	H(2:3)								-.568
Model 3 (CCR>240 grad/Km)									
Predictor		Predicted							
		HiddenLayer 1			HiddenLayer 2				Output Layer
		H(1:1)	H(1:2)		H(2:1)	H(2:2)			V_{85}
Input Layer	(Bias)	-.289	-.576						
	PD	-1.241	-.326						
	CCR_s	-.063	.764						
	R_{cp}	.232	.125						
	W	-.423	-1.344						
	RES	.116	.593						
HiddenLayer 1	(Bias)				.776	.182			
	H(1:1)				-1.042	.194			
	H(1:2)				.944	-.919			
HiddenLayer 2	(Bias)								-.003
	H(2:1)								-1.884
	H(2:2)								.774
Model 4 (CCR<240 grad/Km)									
Predictor		Predicted							
		HiddenLayer 1			HiddenLayer 2				Output

									Layer
		H(1:1)	H(1:2)		H(2:1)	H(2:2)	H(2:3)	H(2:4)	V_{85}
Input Layer	(Bias)	.171	.138						
	PD	.623	-.447						
	W	-.148	.449						
	CCRs	-.480	-.715						
	L	.239	-.229						
	RES	-.646	.152						
	INT	.412	-.696						
	Lpt	-.282	.342						
	CCR	-.379	-.279						
HiddenLayer 1	(Bias)			.302	-.289	-.100	-.257	.302	
	H(1:1)			.255	.282	.622	.791	.255	
	H(1:2)			.716	.445	.845	.126	.716	
HiddenLayer 2	(Bias)								.102
	H(2:1)								.536
	H(2:2)								.648
	H(2:3)								1.142
	H(2:4)								.541

5.2. ANN and empirical model comparison

Figures 2 shows the comparison of the plotted profiles for V_{85} values by using the corresponding ANN models/OLS methods related to geometric features and observed V_{85} values (De Luca and Dell'Acqua, 2012). The profiles show that ANN models offer more reliable results in terms of predicted operating speed than those returned by OLS method on all circular curves and on tangents lengths greater than 500m. For tangents length less than 500 m, OLS method is to be preferred to ANN procedure.

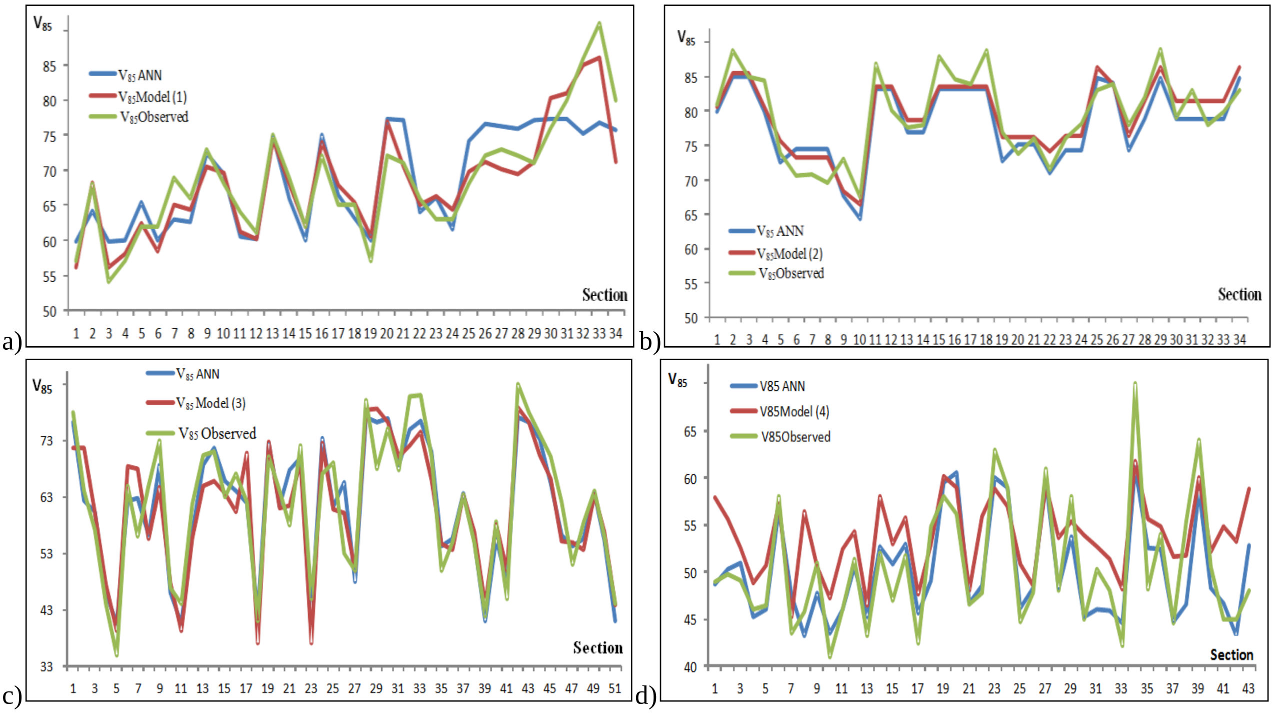


Fig. 2.
Comparing models
a) Tangent Length>500m; b) Tangent Length <500m; c) CCR>240 grad/km; d) CCR<240 grad/km

Table 2 returns a comparison between residuals (difference between Predicted and observed V_{85}) returned by ANN procedure and OLS method for predicting operating speed values.

Table 2
Residuals analysis of predicted operating speed values

Case	ANN Residual	OLS Residual	Mean observed V_{85}	V_{85} Dev. Std.
L>500m	307.0	319.3	77.5	9.03
L<500m	126.5	71.4	68.6	8.13
CCR>240	101.2	200.8	50.4	6.54
CCR<240	171.0	221.2	61.6	11.93

6. Conclusions

The study has shown ANN procedure for calibrating operating speed (V_{85}) prediction models on tangent segments and circular curves on two-lane rural roads in low-volume conditions located in Southern Italy. Predicted V_{85} values coming from ANN procedure and OLS method used in a previous research work of the authors were compared on the same study road network. Two V_{85} prediction models for tangents (greater than and of less than 500 meters) were calibrated, and two V_{85} prediction models on circular curves (curves with a mean CCR value of less than and greater than 240grad/km) were calibrated.The results have shown that the residuals of ANN procedure are in general lower than those calculated by using OLS method for predicting V_{85} value on tangent segments and circular curves with CCR>240grad/km. In particular, it was observed that ANN procedure reaches more consistency than OLS method particularly when the observed speeds present a standard deviation of less than 10 km/h. Future developments are addressed to improve the variables type and to increase the number of study two-lane rural roads in low-volume conditions to give more reliability (Capaldo and Biggiero, 2014; Russo et al., 2013) and effectiveness (Dell'Acqua et al., 2016; De Luca, 2015; Russo et al., 2015) of statistical results.

Acknowledgments

This study was financed by the University of Napoli Federico II as part of the Agreement of Cooperation with the University of Belgrade (Serbia) - Resolution CdAUniNa September 21, 2012.

References

Abbondati, F. et al. 2016. Linear scheduling analysis toolkit for road and airports construction projects, *ARPN Journal of Engineering and Applied Sciences*, 11(11): 6863-6874.

Abdel-Aty, M.; Abdelwahab, H. 2002. Predicting Injury Severity Levels in Traffic Crashes: A Modeling Comparison, *Journal of Transportation Engineering*, 130(2): 204-210.

Alberico, I. et al. 2012. Mapping the vulnerability for evacuation of the CampiFlegrei territorial system in case of a volcanic unrest, *Natural Hazards*, 64(2): 1823-1854.

Capaldo, F.S. 2004a. A behavioral model of flows on roundabouts. In *Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering*, 301-306.

Capaldo, F.S. 2004b. A behavioural driver model for two lane roads. In *Proceedings of 4th International Conference on Traffic and Transportation Studies*, 803-810.

Capaldo, F.S. 2012a. Road Sight Design and Driver Eye Height: Experimental Measures. In *Proceedings of the 5th SIIV International Congress on Sustainability of Road Infrastructure, Procedia Social and Behavioral Sciences*, 732-741.

Capaldo, F.S. 2012b. Passing Maneuver: Survey, Some Models and Simulations.In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 589-597.

Capaldo, F.S. 2012c. Driver Eye Height: Experimental Determination and Implications on Sight Distances. In *Proceeding of the 8th International Conference on Traffic and Transportation Studies (ICTTS)*, 375-383.

Capaldo, F.S.; Grossi, R. 1996. Automatic system for the definition of the setting rules for speed diagrams. In *Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering*, 193-197.

Capaldo, F.S.; Nasti, G. 2012. Analysis of Road Safety: Three Levels of Investigation. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 185-192.

Capaldo, F.S.; Biggiero, L. 2012. Some Surveys in order to Static Traffic Light Coordination. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 313-320.

Capaldo, F.S.; Biggiero, L. 2014. Experimental Survey and Modeling for the Driver Behavior in Vehicle Platoons. In *Proceedings of the 9th International Conference on Traffic and Transportation Studies (ICTTS)*, 279-288.

Capaldo, F.S. et al. 2000a. Accidents and geometric characteristics of road layout: Some quantitative evaluations. In *Proceedings of the 2nd International Conference on Traffic and Transportation Studies (ICTTS 2000)*, 80-87.

Capaldo, F.S. et al. 2000b. Airport capacity according to ICAO rules: Some quantitative evaluations. In *Proceedings 2nd International Conference on Traffic and Transportation Studies (ICTTS 2000)*, 803-810.

Capaldo, F.S. et al. 2012. Passing Maneuver: Models, Surveys and Simulation. In *Proceedings of the 8th International Conference on Traffic and Transportation Studies (ICTTS)*, 790-798.

Čavka, I. et al. 2014. Learning from errors–case study of an aircraft accident. In *Proceedings of the International Conference on Traffic and Transport Engineering*, 444-450.
Čokorilo, O. et al. 2014. Aircraft safety analysis using clustering algorithms, *Journal of Risk Research*, 17(10): 1325-1340.
Dell'Acqua, G. 2011a. Reducing Traffic Injuries Resulting from Excess Speed Low-Cost Gateway Treatments in Italy, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 94-99.
Dell'Acqua, G. 2011b. European speed environment model for highway design-consistency, *Modern Applied Science*, 6(9): 1-10.
Dell'Acqua, G. 2015. Modeling Driver Behavior by using the Speed Environment for Two-Lane Rural Roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2472: 83-90.
Dell'Acqua, G.; Lamberti, R. 2003. A Linear Scheduling Model to Plan Road Works. In *Proceedings of the XXII° World Road Congress*, CD-ROM.
Dell'Acqua, G.; Russo, F. 2010. Speed factors on low-volume roads for horizontal curves and tangents, *The Baltic Journal of Road and Bridge Engineering*, 5(2): 89-97.
Dell'Acqua, G.; Russo, F. 2011a. Road Performance Evaluation Using Geometric Consistency and Pavement Distress Data, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 194-202.
Dell'Acqua, G.; Russo, F. 2011b. Safety Performance Functions for Low-Volume Roads, *The Baltic Journal of Road and Bridge Engineering*, 6(4): 225-234.
Dell'Acqua, G. et al. 2005. Computer Based Linear Scheduling Application for Highway Construction Planning. In *Proceedings of the III° SIIV Congress*, Bari, Italy. CD-ROM.
Dell'Acqua, G. et al. 2011a. Indirect Skid Resistance Measurement for Porous Asphalt Pavement Management, *Transportation Research Record: Journal of the Transportation Research Board*, 2205: 147-154.
Dell'Acqua, G. et al. 2011b. Motorway speed management in southern Italy, *Procedia Social and Behavioral Sciences*, 20: 49-58
Dell'Acqua, G. et al. 2011c. Road safety knowledge-based decision support system, *Procedia Social and Behavioral Sciences*, 20: 973-983.
Dell'Acqua, G. et al. 2011d. Descriptors in Scenic Highway Analysis: a Test Study along Italian Road Corridors, *International Journal for Traffic and Transport Engineering*, 1(2): 73-88.
Dell'Acqua, G. et al. 2012a. Mix Design with Low Bearing Capacity Materials, *The Baltic Journal of Road and Bridge Engineering*, 7(3): 204-211.
Dell'Acqua, G. et al. 2012b. Procedure for Making Paving Decisions with Cluster and Multicriteria Analysis, *Transportation Research Record: Journal of the Transportation Research Board*, 2282: 57-66.
Dell'Acqua, G. et al. 2013a. Safety Data Analysis to Evaluate Highway Alignment Consistency, *Transportation Research Record: Journal of the Transportation Research Board*, 2349: 121-128.
Dell'Acqua, G. et al. 2013b. Risk-type density diagrams by crash type on two-lane rural roads, *Journal of Risk Research*, 16(10): 1297-1314.
Dell'Acqua, G. et al. 2013c. Validation procedure for predictive functions of driver behaviour on two-lane rural roads, *European Transport*, (53) paper 10.
Dell'Acqua, G. et al. 2016. The impact of vehicle movement on exploitation parameters of roads and runways: a short review of the special issue, *Transport*, 31(2): 127-132.
De Luca, M. 2015. A Comparison Between Prediction Power of Artificial Neural Networks and Multivariate Analysis in Road Safety Management, *Transport:* 1-7.
De Luca, M.; Dell'Acqua, G. 2012. Freeway safety management: Case studies in Italy, *Transport*, 27(3), 320-326.
De Luca, M.; Dell'Acqua, G. 2014a. Calibrating the passenger car equivalent on Italian two line highways: A case study, *Transport*, 29(4): 449-456.
De Luca, M.; Dell'Acqua, G. 2014b. Runway surface friction characteristics assessment for LameziaTerme airfield pavement management system, *Journal of Air Transport Management*, 34: 1-5.
De Luca, M. et al. 2011. Before-after freeway accident analysis using Cluster algorithms, *Procedia Social and Behavioral Sciences*, 20: 723-731.
De Luca, M. et al. 2015. Pavement Friction Decay: Preliminary Study in Lamezia Terme International Airport, Italy. In *Proceedings of the Transportation Research Board 94th Annual Meeting*, 15-0126.
De Luca, M. et al. 2016a. Field measurements on runway friction decay related to rubber deposits, *Transport*, 31(2): 177-182.
De Luca, M. e al. 2016b. Preliminary study on runway pavement friction decay using data mining, *Transportation Research Procedia*, 14: 3751-3670.
Discetti, P. et al. 2011. Models of operating speeds for low-volume roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 219-225.
Esposito, T. et al. 2011. Speed prediction models for sustainable road safety management, *Procedia Social and Behavioral Sciences*, 20: 568-576.
Douglas, R.T. et al. 2007. Artificial Neural Network Speed Profile Model For Highspeed Highway Construction Work Zones, *Journal of Transportation Engineering*, 133(3): 198-204.

Esposito, T. et al. 2012. Operating speed prediction models for sustainable road safety management. In *Proceedings of the 14th Euro Working Group on Transportation & 26th Mini Euro Conference & 1st European Scientific Conference on Air Transport*, 712-721.
Faghri, A.; Aneja, S. 1996. Artificial Neural Network–Based Approach To Modeling Trip Production, *Transportation Research Record: Journal of the Transportation Research Board*, 1678: 131-136.
Hassan, A.; Mohamed, A. 2007. Artificial Neural Networks and Logit Models for Traffic Safety Analysis of Toll Plazas, *Transportation Research Record: Journal of the Transportation Research Board*, 1784: 115-125.
Ismai, G.B.; Loo, B.P.Y. 2010. Applying linear analysis methods to GIS-supported procedures for preventing traffic accidents: Case study of Konya, *Safety Science*, 48(6): 763-769.
Lamberti, R. et al. 2010. Visual impact assessment for infrastructure design, *Large Structures and Infrastructures for Environmentally Constrained and Urbanised Areas*: 668-669.
Mauro, R. et al. 2013. Using a k-means clustering algorithm to examine patterns of vehicle crashes in before-after analysis, *Modern Applied Science*, 7(10): 11-19.
Mohammadian, A.; Miller, E.J. 2007. Nested Logit Models and Artificial Neural Networks for Predicting Household Automobile Choices, *Transportation Research Record: Journal of the Transportation Research Board*, 1807: 92-100.
Russo, F. et al. 2013. A statistical look at gender and age differences as related to the injury crash type on low-volume roads, *WIT Transactions on the Built Environment*, 134: 213-224.
Russo, F. et al. 2014a. Road Safety from the Perspective of Driver Gender and Age as Related to the Injury Crash Frequency and Road Scenario, *Traffic Injury Prevention*, 15(1): 25-33.
Russo, F. et al. 2014b. Consistent approach to predictive modeling and countermeasure determination by crash type for low-volume roads, *The Baltic Journal of Road and Bridge Engineering*, 9(2): 77-87.
Russo, F. et al. 2014c. Assessing Transferability of Highway Safety Manual Crash Prediction Models to Data from Italy, *Transportation Research Record: Journal of the Transportation Research Board*, 2433: 129-135.
Russo, F. et al. 2015. Driver Speed Behavior on Circular Curves of Undivided Two-Lane Rural Roads. Serbian and Italian Case Studies, *Transportation Research Record: Journal of the Transportation Research Board*, 2472: 117-128.
Russo, F. et al. 2016a. Safety performance functions for crash severity on undivided rural roads, *Accident Analysis and Prevention*, 93: 75-91.
Russo, F. et al. 2016b. Operating speed as a key factor in studying the driver behavior in a rural context, *Transport*, 31(2): 260-270.
Saito, M.; Fan., J. 1999. Multilayer Artificial Neural Networks for Level-of-Service Analysis of Signalized Intersections, *Transportation Research Record: Journal of the Transportation Research Board*, 1556: 216-224.
Satish, S. et al. 2007. Estimation of Annual Average Daily Traffic on Low-Volume Roads, *Transportation Research Record: Journal of the Transportation Research Board*, 1719: 103-111.
Zilioniene, D. et al. 2013. Evaluation of Climatic Factors Based on the Mechanistic-Empirical Pavement Design Guide, *The Baltic Journal of Road and Bridge Engineering*, 8(3): 158-165.

SPEED DIAGRAMS: AN UPDATED RELATIONSHIP FOR V_{85}

Francesco Saverio Capaldo[1], Demetrio Carmine Festa[2], Francesco Abbondati[3], Mario De Luca[4]
[1,3,4] *Department of Civil, Architectural and Environmental Engineering (DICEA), University of Naples Federico II, Italy,*
[2] *University of Calabria, Rende, Italy*

Abstract: Speed diagrams of rural roads are an essential tool for the good geometric road design, for the control, in existing roads, of the geometrical layout characteristics (visibility distances, coordination between successive elements, the climbing lane for the heavy vehicles). Again they can be used, with information to vehicle weights, to improve sizing of safety barriers. These operations can be successfully performed if it will increase the knowledge of the speed characteristics in road sections with greater accident risk.
There are many studies realized on driver speed, in the last two decades; the resulting values and relationships are different from each other. Every Country has an its own relationship that characterizes the behavior of drivers in road environment: it is not possible to define a single formula for different situations and different drivers. In the paper, in particular, it describes an experimental relationship obtained of the distributions of running speeds of vehicles recorded, in significant periods of time, in different conditions of geometric path and different provinces. The surveys were conducted on various two-lane roads and have allowed to identify a good relationship for the dependence of the operating speed of the layout geometrical elements not only with the free flow speed (FFS, 85th-percentile) and the CCR (curvature change rate), but also with the road longitudinal gradient. It has used the measurements over 40 sections of rural roads with two-lane single carriageway, width greater than 7 meters, long straights and curvature radii greater than 100 meters. The roads are located in Italy, in the provinces of Grosseto, Caserta, Benevento, Cosenza and Naples, with different plan and elevation views of alignment. The environmental conditions of surveys have always been clear weather and daylight. The values obtained were interpolated with different relations and the results were compared with those obtained from other authors in the same geometric conditions.

Keywords: operating speed, prediction models, speed diagrams, driver behavior, infrastructure design, road safety.

1. Introduction

High speed is a major problem in road safety (Benedetto et al., 2004; Capaldo and Nasti, 2012; Dell'Acqua, 2011a; De Luca et al., 2011). The main benefit of high speed traffic flow is that the cost attributed to travel time is reduced, despite higher running costs together with the associated higher environmental costs. The improvements of vehicle performance and road standards promote even higher speeds. The impacts at high speed, however, have a higher kinetic energy and this contributes to increase the severity for the consequences of road accidents.
The driver adopts a behavior that is the compromise between the conditioning due to a number of external factors (road conditions, environmental conditions, etc.) and a series of ability, motivation, internal stimuli (attention, driving ability both physical and mental, etc.). The result of this workload is the spot speed of the vehicle driving: in some favorable conditions, the speed coincides with the desired one; in other cases driver proceeds at a slower speed. Such behavior is always characterized by a series of identifiable factors that allow the study.
In a road section, the value of free flow speed measured fluctuate randomly around a reference value which is constant for all the time in which the environmental conditions (flow, lighting, weather) remain constant. If a parity of every other condition, observation section is changed and it changes on a section with different geometric characteristics, also changes the characteristic value of the measured speed. In the speed realized by drivers (a measure of user behavior) it can be distinguished a systematic component and a random component. The systematic component (the average or an appropriate percentile of speed distributions) varies as function of environmental conditions while the random value varies among the drivers. Still it can distinguish two ways to vary the systematic speed component when varying environmental conditions: in a section, with similar layout conditions, the reference value of the distribution of the instantaneous speed will be a function of traffic flow; along a road path, with a steady flow and not very high, with constant condition of weather and lighting, the changes in instantaneous speed will be related to the geometry of the road. The used value to measure the systematic component of recorded speeds is the 85th-percentile speed, defined as that speed below which 85% of vehicles operate under free flow conditions, on clean, dry road surfaces.
So speed and behavioral study are part of a wide research program that the DICEA is conducting for many years (Capaldo et al., 1997; Capaldo, 2004a; Capaldo, 2004b; Dell'Acqua and Russo, 2010).
The studies that are being carried out on the one hand consider regression models (Ordinary Least-Square Model, OLS) such as the proposed one and the others already mentioned, and on the other consider models based on Artificial Intelligence Computational methods (ACI). In recent years, ACI methods have found Increasing applications in the management of transportation infrastructures. For example many researchers have employed ANN procedures to analyze factors related to data processing. In the scientific papers, many research works have regarded the road safety issues, driver speed behavior or traffic flows. Often on safety procedures is carried an comparison between results coming from ordinary simulation method and/or ANN.
But compare the predicted operating speed on tangents and circular curves for low-volume roads by using two different statistical approaches (ANN versus Ordinary Least-Square Model, OLS) is topic for another paper.

[1] Corresponding author: fcapaldo@unina.it

In this paper shows the results of a never interrupted survey project (Capaldo et al., 1998;) that developed an operating speed prediction models for horizontal curves and tangents on low-volume roads: speed model is associated with the CCR (Curvature Change Rate) value of the curve and with the absolute value of road longitudinal gradient (slope). This relationship has maintained a good validity in time and is now has been revised with new surveys and a more extensive database.

2. Operating speed prediction models

There are many surveys realized on speed, in the last two decades; the resulting values and relationships are different from each other. Every Country has an its own relationship that characterizes the behavior of drivers in the road environment: it is not possible to define a single formula for different situations and different drivers. In the paper, in particular, it describes an experimental relationship obtained of the distributions of running speeds of vehicles recorded, in significant periods of time, in different conditions of geometric path.
Many studies have recorded values for speed on tangents and circular curves. Rather than referring to the simple curve radius, it is preferred to consider the CCR. The *CCR* (Curvature Change Rate) is defined as curvature change rate of the single circular curve with transition curves (clothoids or Euler's spirals). Furthermore, this design parameter includes the influence of the transition curves (in front of and behind the circular curve), and regards the overall length and the deflection angle at the curved sites. CCR, whose analytical value is given by the ratio between the total angular deviation in gon (grads), and the overall length of the curvilinear section, is calculated from the following formula (1):

$$CCR = \frac{Lcl1/2R + Lc/R + Lcl2/2R}{L} * \frac{200}{\pi} * 1000 \approx \frac{Lcl1/2R + Lc/R + Lcl2/2R}{L} * 63700 \quad (1)$$

where:

- *CCR* [gon/km]: Curvature Change Rate;
- *R* [m]: Radius of circular curve;
- L_{cl1} e L_{cl2} [m]: Length of clothoids in front and behind;
- L_c [m]: Length of circular curve;
- L [km] = $L_{cl1} + L_c + L_{cl2}$: Length of curve.

Without regarding transition curves, the formula reads: *CCR* = 63700/R

In order to determine operating speeds, expressed herein by the 85th-percentile speeds, with respect to the curvature change rate of the single circular curve with transition curves (CCR), some known operating speed backgrounds for a number of Countries are given in Table 1.

Table 1
Some empirical relationship of operative speed for rural roads with two bidirectional lanes for a number of countries and their speed limits

Country	Speed Limit	V_{85}	*Coefficient of determination* R^2	
Germany	100	$10^6/(8270+8.01\bullet CCR)$	0.73	(2)
USA	90	$103.04-0.053\bullet CCR$	0.80	(3)
Grece	110	$10^6/(10150.1+8.529\bullet CCR)$	0.81	(4)
France	90	$102/\left[1+346/(63700/CCR)^{1.5}\right]$	-	(5)
Italy	90	$(118-1.8\lvert i\%\rvert)\bullet(1-34.61/R)$ $(118-1.8\lvert i\%\rvert)\bullet(1-CCR/1870)^2$	0.91, (Capaldo et. al., 1998)	(6)
		$93.96-57.3\bullet CCR+20\bullet CCR^2$	0.86, (IASPIS, 2001)	(7)
Lebanon	90	$91.03-0.056\bullet CCR$	0.81	
Australia	90	$101.2-0.075\bullet CCR$	0.87	(8)

Adapted from Lamm et al. (1999)

In Table 1 only the relationship (6) considers the speed change due to *R* or *CCR* and also to the absolute value of the longitudinal slope (|*i%*|).
Four prediction models were later developed by Ordinary Least-Square Model (OLS) Method (Dell'Acqua and Russo,

[2] Relationship shows in this form (with CCR) for the first time since its publication.

2011) for the analyzed roadways: two models on tangents and two models on the circular curves. Speed observations on the circular curves with a radius greater than 500 meters were included in the same database of tangents because drivers' behavior is very similar to that adopted on the tangent segments. The models were created using multiple correlations. All parameters included in the models are significant with a 95% confidence level. The best specification of the OLS model of operating speeds on tangents, in kilometers per hour, with a length greater than 500 meters is as follows with adjusted coefficient of determination (R^2) of the model equal to 0.83:

$$V_{85T} = 59.16 + 0.20 \cdot W^2 - 0.023 \cdot CCR_S + 10^{-5} \cdot {CCR_S}^2 - 0.69 \cdot RES + 8.8 \cdot 10^{-2} \cdot R_{PC} - 3.5 \cdot 10^{-4} \cdot R_{PC}^2 - 2.63 \cdot PD \tag{9}$$

The best specification of the OLS model for operating speeds on the tangents with a length of less than 500 meters, in kilometers per hour, is as follows with R^2 equal to 0.89:

$$V_{85T} = 61.56 + 2.4 \cdot 10^{-4} \cdot R_{PC}^2 - 0.11 \cdot R_{PC} + 0.017 \cdot D - 3.29 \cdot INT + 0.30 \cdot V_{85PC} - 3.41 \cdot PD \tag{10}$$

The best specification of the OLS model for operating speeds on horizontal curves with a mean CCR value of less than 240gon/km, in kilometers per hour, is as follows with R^2 equal to 0.81:

$$V_{85C} = 55.74 + 5.57 \cdot W - 0.038 \cdot CCR_S + 10^{-5} \cdot {CCR_S}^2 - 0.03 \cdot L - 0.48 \cdot RES - 4.65 \cdot INT + 7.3 \cdot 10^{-4} \cdot L_{PT} - 0.064 \cdot CCR - 0.30 \cdot PD \tag{11}$$

The best specification of the OLS model for operating speeds on horizontal curves with a mean CCR value greater than 240 gon/km, in kilometers per hour, is as follows with R^2 equal to 0.72:

$$V_{85C} = 59.16 + 0.20 \cdot W^2 - 0.023 \cdot CCR_S + 10^{-5} \cdot {CCR_S}^2 - 0.69 \cdot RES + 8.8 \cdot 10^{-2} \cdot R_{PC} - 3.5 \cdot 10^{-4} \cdot R^2{}_{PC} - 2.63 \cdot PD \tag{12}$$

where:

- V_{85T} = predicted operating speed value on tangent segment (km/h);
- L= total tangent length (m);
- R_{PC}= radius of the preceding curve (m);
- V_{85PC}= operating speed in the middle section of the preceding curve (km/h);
- INT= intersection indicator, which is equal to 1 if the intersection is located 150 m before or after the surveyed location and 0 otherwise;
- PD= pavement distress indicator, which is equal to 0 if pavement distress is absent, which means that the pavement condition does not influence the driver free-speed behavior, and which is greater than 0 if the level of pavement distress is not low and this condition negatively influences the driver speed behavior, causing a speed decrease (1 if the distress is low, 2 if the distress is high, and 3 if the distress is very high);
- D= distance from the survey point from the end section of the preceding horizontal curve (in meters);
- V_{85C}= predicted operating speed on horizontal circular curve (km/h);
- W= width of travel lanes plus shoulders (m);
- RES= number of residential driveways per kilometer;
- LPT= length of preceding tangent (m).

The relationship (6) shown in Table 1 was proposed already in the late '90. This had a good R^2 (0.91) among all other correlations but the data base on which had been validated consisted of 16 velocity distributions recorded on 6 low-volume roads with carriageway width more than 7 m, with radii not less than 200 m and longitudinal gradients not more than 7%. The survey sections were all far from intersections and on paths with tangents of at least 500 m. The good correlation was obtained with an essential formulation which had consider only two parameters. The project was never abandoned and it was consistently increased the data base and carried out sample verifies in order to possible corrections on older speed distributions.

In this note it proposes latest revision of this relationship in function of a series of new surveys that have led to over 40 of the data recording sections.

3. Data acquisition, analysis and relationship structure

The experimental survey of this study started out as one of the principle objectives in amplifying the samples of available data relative to the speed analysis. The acquisition of the necessary data, if it do not have specific devices to automatic recording, is an intensive work in terms of time. The measurements were made using videos shot with cameras on sections of low-volume roads with two-lane, single carriageway and using measured bases. The system remains preferable to others because it allows possible control of numerical faults through a repeat of the analysis of recorded images.

For each survey beforehand were known the geometrical characteristics of the paths of which the sections were elements. During the video taking it has always had the attention of hide the devices to prevent drivers could exchange

these as approved speed detectors (radar type, speed cameras and the like). Video devices was positioned always sideways and out of to the road.
The new surveys available were 43 and were carried out on sections of state roads in the provinces of Benevento, Caserta, Cosenza, Grosseto and Naples, with different horizontal and vertical layout characteristics. All measurements were made in clear weather and daylight. In Fig. 1 and 2 two images of the SS 88 about to 82 km in the travel direction from Campobasso to Benevento.

Fig. 1.
SS 88 at km 82.650 in the direction from Campobasso to Benevento

Fig. 2.
SS 88 at km 82.450 in the direction from Campobasso to Benevento

The tangent sections were 26, horizontal curves with constant radius 17 with a minimum radius of 90 m and a maximum of 800 m. The flat sections were 21, those with some longitudinal slope were 22, with a maximum of 7%. The road width was always greater than about 8 m (7.80 m).
For each of the investigated sections and for each vehicle it have been recorded transit times between the delimiting sights on the measured basis, obtaining the following data: type of vehicle, direction of origin, transit time on the first relative sight, speed, distance from the vehicle preceding.
Given that it is always worked with bases measured between 20 and 30 m, the recorded speed can be considered instantaneous. To compare the speed measurements it is always referred to measurements carried out in low traffic conditions using the flow diagrams, with the flow rates expressed in equivalent cars per hour.
The flow diagrams representing the relation between flows and speeds in a road section: when traffic conditions changing (flow rate) it records the corresponding speed variations. Is possible to obtain a diagram in which the flow rates are constituted only by «passenger cars» if calculates a coefficient of equivalence for the commercial means (heavy). Working, then, with the flow-speed diagrams and with capacity expressed in equivalent cars/hours, it has eliminated the interferences due to the various traffic flows and their heterogeneous composition (passenger cars and trucks).

4. Data analysis, relationship structure and results

The surveyed data were necessary to search a relation between the geometric road characteristics and the so-called operating speed (FFS or maximum 85th-percentile value of the speeds surveyed on long tangents), because it represents «the speed which drivers tend to go at when they are not conditioned by traffic or by horizontal alignment».
This parameter of the velocity distributions was evaluated using the CCR and road longitudinal gradient (slope).
Compared to the original formulation (Capaldo et al., 1997) it is preferred to leave the old parameter R and to privilege the most diffused JRC, recalling the perfect equivalence (less than some scale factors) between the two parameters if there are no clothoids on the circular curves.

Table 2
Correlations of V_{85} with other recorded data as the roadway width, the absolute value of the longitudinal slope, the CCR and also intersections/km or intersection factor

	V_{85}	Road. Width	|i%|	CCR	Int./km	Int. Factor
V_{85}	1					
Road. Width	-0,22885	1				
|i%|	-0,32958	0,331712	1			
CCR	-0,88427	0,158298	0,072008	1		
Int./km	-0,27383	-0,128760	-0,013150	0,214628	1	
Int. Factor	-0,20146	-0,093530	0,127715	0,154211	0,750982	1

The recorded data include for each section: 85th-percentile value of the speeds, the width of the roadway, the absolute value of the longitudinal slope, the CCR. It has also recorded information on interference to the uninterrupted flows by intersections as the number of them or another correlated value for km. In Table 2 are shown the correlations of all these factors registered.

The carriageway width, as also indicated various works, influence the speed only if it is clearly less than 7 m. At this point of the investigation, the correlations with intersection data, or with a value related, appear be as little significant. It remains to investigate the correlation between the absolute value of the longitudinal slope and the CCR.

By multiple regressions of speed on the absolute value of the longitudinal slope and the CCR have been obtained coefficients for the relationship:

$$V_{85} = a_0 + a_1 * |i\%| + a_2 * CCR \tag{13}$$

$$V_{85} = 119.20 + 1.33 * |i\%| - 0.057 * CCR \tag{14}$$

Where a_0 is the running speed on a flat tangent; $|i\%|$ is the absolute value of the longitudinal slope. The analysis has furnished for the relationship (14) the coefficient of determination R^2 of 0.853 (Fig. 3). The basic structure of the interpolation relationship has been modified in the form the (15) to considering that the running speed in a curved section is a function not only of the radius of curvature but also of the approach speed to the curve itself which generally is a function of the characteristics of the path.

$$V_{85} = (a_0 + a_1 * |i\%|) + (a_0 + a_1 * |i\%|) * a_3 * CCR = (a_0 + a_1 * |i\%|) + (1 + CCR/a_3) \tag{15}$$

$$V_{85} = (119.20 - 1.33 * |i\%|) + (1 - CCR/2034) \tag{16}$$

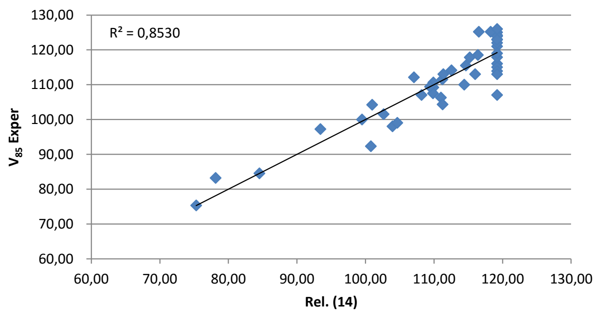


Fig. 3.
Experimental speed versus the calculated speed with the report (14) and coefficient of determination (R^2)

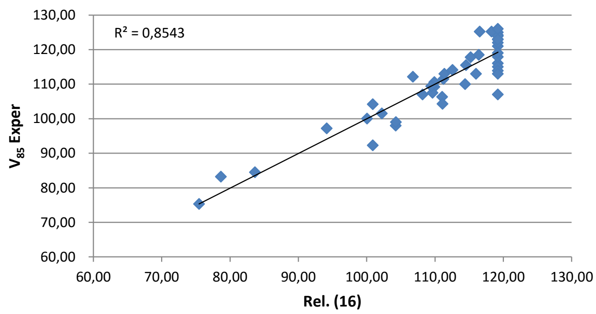


Fig. 4.
Experimental speed versus the calculated speed with the report (16) and coefficient of determination (R^2)

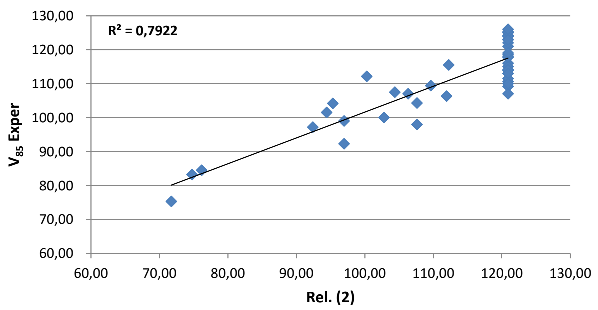


Fig. 5.
Experimental speed versus the calculated speed with the report (2) and coefficient of determination (R^2)

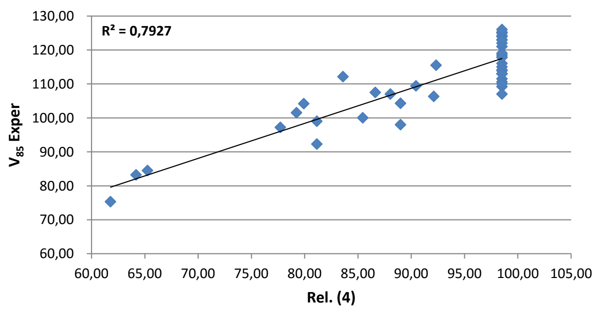


Fig. 6.
Experimental speed versus the calculated speed with the report (4) and coefficient of determination (R^2)

The coefficient a_3 of the (15) is equal to 2034 in the (16). It was obtained by making minimum the sum of the differences squares of the experimental speed values on curve and those obtained from the (16). For this latter relationship is obtained a coefficient of determination R^2 0.854 (Fig. 4).

5. Results comparison

The relation (16) has a best fit to the experimental data. It requires little information to provide a very reliable value of the desired speed. It would be interesting to operate also a comparison with the results of the shows relationships from (9) to (12) but they need a larger number of parameters which were not available by surveys made, or, at least, they were only partly.

It was decided to compare the experimental surveying data with some more similar relationship, and it chose to utilize, among those including in Table 1, the relations (2) and (4) relating to two Countries such as Germany and Greece. The Table 3 shows some examples between the compared values and, in the ending rows, they are summarized the minimum, maximum and average of the absolute values of the percentage differences between the experimental and data calculated with the corresponding relationship. The two Fig. 5 and Fig. 6 show the complete graphs of the values calculated with the two cited relationship and those of the starting experimental data, They indicate a good degree of adaptation of the two relation to the data, although much lower than that of the report (16).

Table 3

Comparison between some values of the experimental data and the values calculated with the relationship (16), (2) and (4), percentage differences with these and minimum, maximum and average of the absolute values of these differences

Rif.	*Exp. V_{85}*	*Rel (16)*	*Diff% (16)*	*Rel (2)*	*Diff% (2)*	*Rel (4)*	*Diff% (4)*
1	123,00	119,20	3,09	120,92	1,69	98,52	19,90
2	84,50	83,65	1,01	76,16	8,34	65,26	19,24
3	75,30	75,47	-0,22	71,74	3,56	61,78	13,52
4	116,00	119,20	-2,76	120,92	4,92	98,52	17,48
5	115,00	119,20	-3,65	120,92	5,92	98,52	16,48
6	92,30	100,90	-9,31	96,98	4,68	81,15	11,15
7	121,00	119,20	1,49	120,92	0,08	98,52	22,48
8	113,00	116,01	-2,67	120,92	7,92	98,52	14,48
9	101,50	102,23	-0,72	94,44	7,06	79,24	22,26
10	109,20	109,90	-0,64	120,92	-11,72	98,52	10,68
11	100,00	100,07	-0,07	102,80	-2,80	85,45	14,55
12	110,60	109,90	0,63	120,92	-10,32	98,52	12,08
13	98,00	104,26	-6,39	107,64	-9,64	88,99	9,01
14	111,50	111,23	0,24	120,92	-9,42	98,52	12,98
15	125,00	119,20	4,64	120,92	4,08	98,52	26,48
16	117,90	119,20	-1,10	120,92	-3,02	98,52	19,38
…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…
38	122,90	119,20	3,01	120,92	1,98	98,52	24,38
39	110,00	114,42	-4,02	120,92	10,92	98,52	11,48
40	83,20	78,67	5,44	74,78	8,42	64,17	19,03
41	126,00	119,20	5,40	120,92	5,08	98,52	27,48
42	119,00	119,20	-0,17	120,92	1,92	98,52	20,48
43	99,00	104,27	-5,32	96,98	2,02	81,15	17,85
Diff% min			*0,05*		*0,08*		*8,48*
Diff% max			*11,40*		*13,92*		*28,49*
Diff% average			*3,23*		*5,40*		*18,65*

Where: Exp. V_{85}: 85th percentile of measured experimental speed (km/h); Rel. (xx): resulted speed form relationship (xx); Diff% (XX): percentage difference between the calculated value with the relationship (XX) that of the experimental V_{85}; Diff% min, max, average: minimum, maximum and average of the absolute values of percentage difference.

4. Some considerations

The regression analysis was conducted only on specified parameters. To make the speeds analysis independent by traffic flows it has worked with the flow diagrams made for each survey. It may be noted that the speed of certain sections were different from those which might have been expected under the same geometric conditions. The drivers proceeded more slowly because of the presence of a some number of intersections along the way. It has tried some correlations directly with information as number of intersections per km and/or for the direction of travel, as well as with numeric values that could derive from this basic information. To date the results have not been satisfactory and it must wait for a future survey research in order to investigate this further step.

The wider data base has led to a relationship not too different from that proposed in the past and the relative increase of the interpolation constants was due more to the data increase that the small difference in the control values on old surveys.

5. Conclusion

The study of the relationship between speed and environmental parameters (road, geometric characteristics, lighting, pavement conditions, visibility, etc.) is important to formulate best criteria for the road design and for the verification of existing roads, criteria which are more close to reality. It 'a study necessary but costly, in terms of time, and the results are valid in the territorial areas not too large. The reason that influences the location of the expressions is on the one hand the difference between the methodologies related to construction of the infrastructures , especially, the orography of the various Countries and on the other hand, certainly not secondary factor, is the difference of driver behaviors.
Sure the speed study through an extensive database related on driving events, realize a picture of what can be defined as the product of emotional experiences of drivers which are reflected in the control, or less, of the velocity vector and with this in control of their passenger cars. And for this reason the relationships like the one presented contribute to the provision of this aspect of the driving behavior. Furthermore, through the knowledge of some basic factors (bending radius and longitudinal slope) that have been shown to influence drivers, it can try to intervene to change, to the benefit of safety.

References

Abbondati, F. et al. 2016. Linear scheduling analysis toolkit for road and airports construction projects, *ARPN Journal of Engineering and Applied Sciences*, 11(11): 6863-6874.

Alberico, I. et al. 2012. Mapping the vulnerability for evacuation of the Campi Flegrei territorial system in case of a volcanic unrest, *Natural Hazards*, 64(2): 1823-1854.

Aljanahi, A.A.M. et al. 1999. Speed, speed limits and road traffic accidents under free flow conditions, *Accident Analysis and Prevention*, 31: 161-168.

Bella, F. 2005. The evaluation of Design Consistency: Predicting Models of Operating Speed on Three-Dimensional Alignment from Tests on Driving Simulator. In *3rd International Symposium on Highway Geometric Design*, Chicago, U.S.A.

Benedetto, A. et al. 2004. A new effective approach to accidents prediction to improve roads' design and rehabilitation, *Advances in Transportation Studies an international Journal*, Section A 4, Vol. IV, November.

Capaldo, F.S.; Grossi, R. 1996. Automatic system for the definition of the setting rules for speed diagrams. In *Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering*, 193-197.

Capaldo, F.S. et al. 1997. I diagrammi di velocità e la sicurezza stradale. In *La sicurezza intrinseca delle infrastrutture stradali.* Roma 20-21 Febbraio 1997, 97-112.

Capaldo, F.S. et al. 1998. I diagrammi di velocità e la sicurezza stradale. In *54a Conferenza del traffico e della circolazione.* Riva del Garda 7-10 ottobre 1998, 262-269.

Capaldo, F.S. et al. 2000a. Accidents and geometric characteristics of road layout: Some quantitative evaluations. In *Proceedings of the 2nd International Conference on Traffic and Transportation Studies (ICTTS 2000)*, 80-87.

Capaldo, F.S. et al. 2000b. Airport capacity according to ICAO rules: Some quantitative evaluations. In *Proceedings 2nd International Conference on Traffic and Transportation Studies (ICTTS 2000)*, 803-810.

Capaldo, F.S. 2004a. A behavioral model of flows on roundabouts. In *Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering*, 301-306.

Capaldo, F.S. 2004b. A behavioural driver model for two lane roads. In *Proceedings of 4th International Conference on Traffic and Transportation Studies*, 803-810.

Capaldo, F.S. 2012a. Passing Maneuver: Survey, Some Models and Simulations. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 589-597.

Capaldo, F.S. 2012b. Driver Eye Height: Experimental Determination and Implications on Sight Distances. In *Proceedings in the 8th International Conference on Traffic and Transportation Studies (ICTTS)*, 375-383.

Capaldo, F.S. 2012c. Road Sight Design and Driver Eye Height: Experimental Measures. In *Proceedings of the 5th SIIV International Congress on Sustainability of Road Infrastructure, Procedia Social and Behavioral Sciences*, 732-741.

Capaldo, F.S. et al. 2012. Passing Maneuver: Models, Surveys and Simulation. In *Proceedings in the 8th International Conference on Traffic and Transportation Studies (ICTTS)*, 790-798.

Capaldo, F.S.; Biggiero, L. 2012. Some Surveys in order to Static Traffic Light Coordination. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 313-320.

Capaldo, F.S.; Nasti, G. 2012. Analysis of Road Safety: Three Levels of Investigation. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 185-192.

Capaldo, F.S.; Biggiero, L. 2014. Experimental Survey and Modeling for the Driver Behavior in Vehicle Platoons. In *Proceedings of the 9th International Conference on Traffic and Transportation Studies (ICTTS)*, 279-288.

Čavka, I. et al. 2014. Learning from errors-case study of an aircraft accident. In *Proceedings of the International Conference on Traffic and Transport Engineering*, 444-450.

Chowdhury, M.A. et al. 1991. Analysis of Advisory Speed Setting Criteria, *Public Roads*, 55(3): 65-71.
Čokorilo, O. et al. 2014. Aircraft safety analysis using clustering algorithms, *Journal of Risk Research*, 17(10): 1325-1340.
Dell'Acqua, G. 2011a. Reducing Traffic Injuries Resulting from Excess Speed Low-Cost Gateway Treatments in Italy, *Transportation Research Record*, 2203: 94-99.
Dell'Acqua, G. 2011b. European speed environment model for highway design-consistency, *Modern Applied Science*, 6(9): 1-10.
Dell'Acqua, G. 2015. Modeling Driver Behavior by using the Speed Environment for Two-Lane Rural Roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2472: 83-90.
Dell'Acqua, G.; Lamberti, R. 2003. A Linear Scheduling Model to Plan Road Works. In *Proceedings of the XXII° World Road Congress*, CD-ROM.
Dell'Acqua, G.; Russo., F. 2010. Speed factors on low-volume roads for horizontal curves and tangents, *The Baltic Journal of Road and Bridge Engineering*, 5(2): 89-97.
Dell'Acqua, G.; Russo, F. 2011a. Safety Performance Functions for Low-Volume Roads, *The Baltic Journal of Road and Bridge Engineering*, 6(4): 225-234.
Dell'Acqua, G.; Russo, F. 2011b. Road Performance Evaluation Using Geometric Consistency and Pavement Distress Data, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 194-202.
Dell'Acqua, G. et al. 2005. Computer Based Linear Scheduling Application for Highway Construction Planning. In *Proceedings of the III° SIIV Congress*, Bari, Italy. CD-ROM.
Dell'Acqua, G. et al. 2007. Field Studies on Posted Speed Limits. In *Proceedings of the International Conference Road Safety and Simulation (RSS)*, 7-8-9th November, Rome, Italy.
Dell'Acqua, G. et al. 2011a. Road safety knowledge-based decision support system, *Procedia Social and Behavioral Sciences*, 20: 973-983.
Dell'Acqua, G. et al. 2011b. Motorway speed management in southern Italy, *Procedia Social and Behavioral Sciences*, 20: 49-58.
Dell'Acqua, G. et al. 2011c. Indirect Skid Resistance Measurement for Porous Asphalt Pavement Management, *Transportation Research Record: Journal of the Transportation Research Board*, 2205: 147-154.
Dell'Acqua, G. et al. 2011d. Descriptors in Scenic Highway Analysis: a Test Study along Italian Road Corridors, *International Journal for Traffic and Transport Engineering*, 1(2): 73-88.
Dell'Acqua, G. et al. 2012a. Procedure for Making Paving Decisions with Cluster and Multicriteria Analysis, *Transportation Research Record: Journal of the Transportation Research Board*, 2282: 57-66.
Dell'Acqua, G. et al. 2012b. Mix Design with Low Bearing Capacity Materials, *The Baltic Journal of Road and Bridge Engineering*, 7(3): 204-211.
Dell'Acqua, G. et al. 2013a. Safety Data Analysis to Evaluate Highway Alignment Consistency, *Transportation Research Record: Journal of the Transportation Research Board*, 2349: 121-128.
Dell'Acqua, G. et al. 2013b. Risk-type density diagrams by crash type on two-lane rural roads, *Journal of Risk Research*, 16(10): 1297-1314.
Dell'Acqua, G. et al. 2013c. Validation procedure for predictive functions of driver behaviour on two-lane rural roads, *European Transport*, (53) paper 10.
Dell'Acqua, G. et al. 2016. The impact of vehicle movement on exploitation parameters of roads and runways: a short review of the special issue, *Transport*, 31(2): 127-132.
De Luca, M. 2015. A Comparison Between Prediction Power of Artificial Neural Networks and Multivariate Analysis in Road Safety Management, *Transport:* 1-7.
De Luca, M.; Dell'Acqua, G. 2012. Freeway safety management: Case studies in Italy, *Transport*, 27(3), 320-326.
De Luca, M.; Dell'Acqua, G. 2014a. Runway surface friction characteristics assessment for Lamezia Terme airfield pavement management system, *Journal of Air Transport Management*, 34: 1-5.
De Luca, M.; Dell'Acqua, G. 2014b. Calibrating the passenger car equivalent on Italian two line highways: A case study, *Transport*, 29(4): 449-456.
De Luca, M. et al. 2011. Before-after freeway accident analysis using Cluster algorithms, *Procedia Social and Behavioral Sciences*, 20: 723-731.
De Luca, M. et al. 2015. Pavement Friction Decay: Preliminary Study in Lamezia Terme International Airport, Italy. In *Proceedings of the Transportation Research Board 94th Annual Meeting*, 15-0126.
De Luca, M. et al. 2016a. Field measurements on runway friction decay related to rubber deposits, *Transport*, 31(2): 177-182.
De Luca, M. et al. 2016b. Preliminary study on runway pavement friction decay using data mining, *Transportation Research Procedia*, 14: 3751-3670.
Discetti, P. et al. 2011. Models of operating speeds for low-volume roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 219-225.
Esposito, T. et al. 2011. Speed prediction models for sustainable road safety management, *Procedia Social and Behavioral Sciences*, 20: 568-576.
Esposito, T. et al. 2012. Operating speed prediction models for sustainable road safety management. In *Proceedings of the 14th Euro Working Group on Transportation & 26th Mini Euro Conference & 1st European Scientific Conference on Air Transport*, 712-721.

Fambro, D.B. et al. 1997. Determination of Stopping Sight Distances. *NCHRP Report 400*, Transportation Research Board, Washington, DC.
Fitzpatrick, K. et al. 1995. Compatibility of Design Speed, Operating Speed, and Posted Speed. *Final Report FHWA/TX-95/1465-2F.* Texas Department of Transportation, College Station, TX, October.
Fitzpatrick, K. et al. 1999. Design Factors That Affect Driver Speed on Suburban Arterials. *Report FHWA/TX-00/1769-3*. Texas Transportation Institute, College Station, TX, August.
Fitzpatrick, K. et al. 2000. Speed Prediction for Two-Lane Rural Highways. *Report FHWA-RD-99-171*. Federal Highway Administration, Washington, DC.
Fitzpatrick, K. et al. 2003. Design speed, operating speed, and posted speed limit practice. *NCHRP 504*, Transportation Research Board, Washington, DC.
Haglund, M.; Aberg, L. 2000. Speed choice in relation to speed limit and influences from other drivers, *Transportation Research Part F 3*, 39-51.
IASPIS, 2001. Interazione Ambiente Sicurezza nel Progetto delle Infrastrutture Stradali, Rapporto Conclusivo del Progetto di Ricerca IASPIS, Firenze.
ITE Technical Committee 97-12, Parma, K.. chair 2001. Survey of Speed Zoning Practices. *ITE Informational Report*. Institute of Transportation Engineers, Washington, DC.
Johnson, S.L.; Pawar, N. 2007. Analysis of heavy truck and automobile speed distributions for uniform and differential speed limit configurations on rural interstate highways. In *Transportation Research Board Annual Meeting Proceedings*.
Krammes, R.A. et al. 1994. Horizontal Alignment Design Consistency for Rural Two-Lane Highways. *Research Report FHWA-RD-94-034*. Federal Highway Administration, Washington, DC.
Lamberti, R. et al. 2010. Visual impact assessment for infrastructure design, *Large Structures and Infrastructures for Environmentally Constrained and Urbanized Areas*: 668-669.
Lamm, R. et al. 1999. *Highway design and traffic safety engineering handbook*, Mcgraw-Hill, New York.
Mauro, R. et al. 2013. Using a k-means clustering algorithm to examine patterns of vehicle crashes in before-after analysis, *Modern Applied Science*, 7(10): 11-19.
Parker, M.R.Jr. 1985. Synthesis of Speed Zoning Practices. *Publication No. FHWA-RD-85-096*. Federal Highway Administration, Washington, DC, July.
Parker, M.R.Jr. 1992. Comparison of Speed Zoning Procedures and Their Effectiveness. *Final Report, prepared for the Michigan Department of Transportation*. Lansing, Michigan, September.
Parker, M.R.Jr. 1997. Effects of Raising and Lowering Speed Limits on Selected Roadway Sections, Final Report. *Publication No. FHWA-RD-92-084*. Federal Highway Administration, Washington, DC, January.
Psarianos, B. et al. 2007. Attitudes of Greek drivers towards posted speed limits. In *4th International SIIV Congress Proceedings*, Palermo, Italy.
Russo, F. et al. 2013. A statistical look at gender and age differences as related to the injury crash type on low-volume roads, *WIT Transactions on the Built Environment*, 134: 213-224.
Russo, F. et al. 2014a. Road Safety from the Perspective of Driver Gender and Age as Related to the Injury Crash Frequency and Road Scenario, *Traffic Injury Prevention*, 15(1): 25-33.
Russo, F. et al. 2014b. Consistent approach to predictive modeling and countermeasure determination by crash type for low-volume roads, *The Baltic Journal of Road and Bridge Engineering*, 9(2): 77-87.
Russo, F. et al. 2014c. Assessing Transferability of Highway Safety Manual Crash Prediction Models to Data from Italy, *Transportation Research Record: Journal of the Transportation Research Board*, 2433: 129-135.
Russo, F. et al. 2015. Driver Speed Behavior on Circular Curves of Undivided Two-Lane Rural Roads. Serbian and Italian Case Studies, *Transportation Research Record: Journal of the Transportation Research Board*, 2472: 117-128.
Russo, F. et al. 2016a. Safety performance functions for crash severity on undivided rural roads, *Accident Analysis and Prevention*, 93: 75-91.
Russo, F. et al. 2016b. Operating speed as a key factor in studying the driver behavior in a rural context, *Transport*, 31(2): 260-270.
Schurr, K.S. et al. 2002. Relationship Between Design, Operating and Posted Speeds on Horizontal Curves on Rural Two-Lane Highways in Nebraska. In *Transportation Research Board Annual Meeting Proceedings*.
Stamtiadis, N.; Gong, H. 2007a. Analysis of inconsistencies related to design speed, operating speed and posted speed limit. In 4th *International SIIV Congress Proceedings*, Palermo, Italy.
Stamatiadis, N.; Gong, H. 2007b. Analysis of Inconsistencies Related to Design Speed, Operating Speed, and Speed Limits. Kentucky Transportation Research Center *Report KTC-06-12*, College of Engineering, University of Kentucky, Lexington, KY, March.
Zilioniene, D. et al. 2013. Evaluation of Climatic Factors Based on the Mechanistic-Empirical Pavement Design Guide, *The Baltic Journal of Road and Bridge Engineering*, 8(3): 158-165.

MODELING POSTED SPEED LIMITS FOR LOW-VOLUME ROADS

Francesco Abbondati[1], Renato Lamberti[2], Francesco Saverio Capaldo[3], Giovanni Coraggio[4]
[1,2,3] Department of Civil, Architectural and Environmental Engineering (DICEA), University of Naples Federico II, Italy
[4] Mobility and Transport Section, Province of Salerno, Italy

Abstract: Speeding is a general problem in traffic and exploring factors underlying the choice of speed is an important task. The relationship between various measures of traffic speed, under free flow conditions, and speed limits is investigated for two groups of sites in southern Italy. The effect of speed limits on traffic speed is estimated for both groups of sites.

Keywords: driver behavior, design, safety, speed limit.

1. Introduction

High speed is a major problem in road safety (Benedetto et al., 2004; Capaldo and Nasti, 2012; Dell'Acqua, 2011a; De Luca et al., 2011). The main benefit of high speed traffic flow is that the cost attributed to travel time is reduced, despite higher running costs together with the associated higher environmental costs. The improvements of vehicle performance and road standards promote even higher speeds. Increased speeding will likely result in augmenting the number of traffic accidents, as well as the severity of the injuries, resulting from high-speed accidents. Many drivers are aware of the negative effects of speed, exceeding the speed limit is nevertheless one of the most frequent traffic violations. A feature of road safety is that inferences based on statistical information from individual studies are often imprecise. Designers need to take expert judgment and results from similar surveys into account when drawing conclusions. Traditional approaches have many points of weakness connected to the inadequacy of the accident database and to the low reliability of statistical methods for the diagnosis of the cause. Techniques based on artificial intelligence have been investigated (De Luca, 2015; Mauro et al., 2013). Hazard analysis approach has given important, very applicable and reliable results (Russo et al., 2014b; Russo et al., 2016a). The best point estimates for the link between speed and accidents suggest that the number of accidents could be substantially reduced; by either enforcing lower speed limits or at least reducing the spread of vehicle speeds. To determine the attitudes of drivers towards speed limits and understand their behavior, a survey (Figure 1) of Italian drivers was undertaken in two roadway environments.

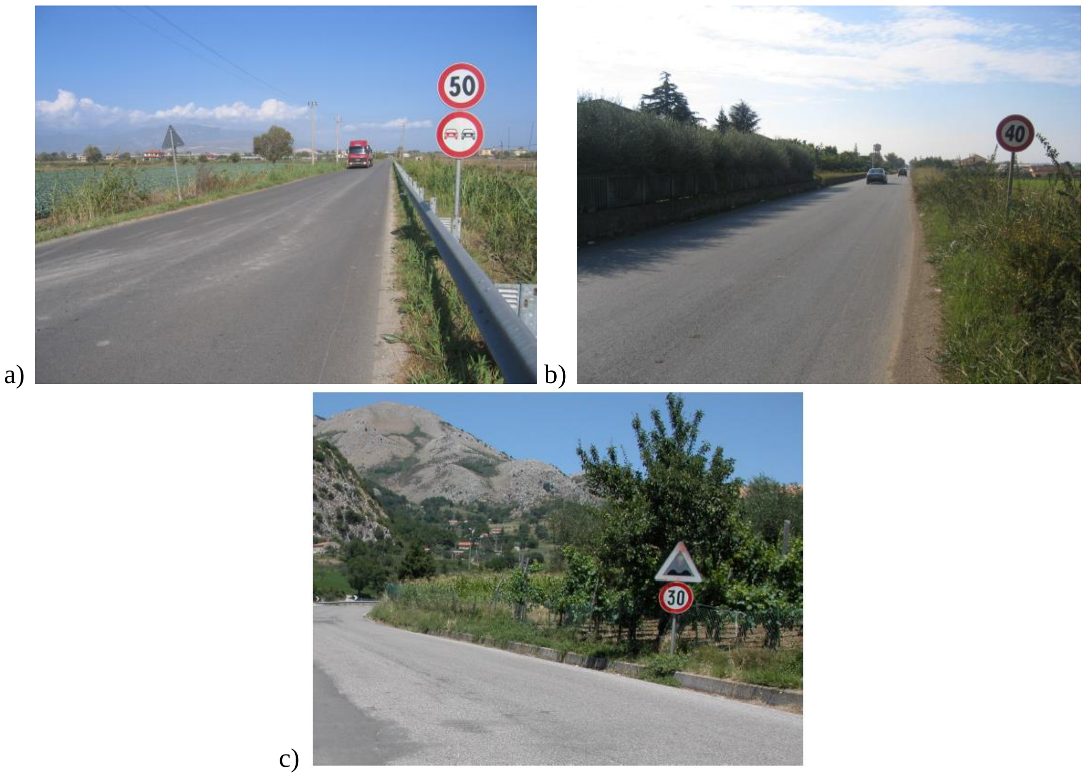


Fig. 1.
a) Posted speed limit on tangent of SP312; b) on tangent of SP30b; c) on curve of SS166

Speed limits are the usual means of controlling vehicle speeds under free flow conditions on high speed road links. Their efficiency depends, partly, on the level of policing and the size of penalties. It is generally acknowledged that

[1] Corresponding author: francesco.abbondati@unina.it

85th percentile operating speeds exceed posted speeds (Fambro et al., 1997; Fitzpatrick et al., 1995; Fitzpatrick et al., 1999; Fitzpatrick et al., 2000; Krammes et al., 1994; Parker, 1997). Bella (2005) in Italy proposed relationships between operating speed and other road features using driving simulator. Many of these reports have also demonstrated, in USA, that the 50th percentile operating speed either is near or exceeds the posted speed limit. The methods used to set speed limits have been reviewed by several authors (Parker, 1985; Parker, 1992). A review was conducted by an Institute of Transportation Engineers Technical Committee (2001) with the following findings. Also, in Sweden, it was found that most of the drivers exceeded the 90 km/h speed limit, a finding that corresponds with previous research (Haglund and Aberg, 2000). The relationship between various measures of traffic speed, under free flow conditions, and accident rate is investigated for two groups of sites, one in the Tyne and Wear County of the UK and the other in Bahrain (Aljanahi et al., 1999). The results suggest that speed limits are a reasonably effective means of reducing traffic speed in free flow conditions. The effects of speed limit (SL), percentage of heavy vehicles (HV), number of lanes (L), trip length (TL) and length of section (LS) were statistically significant despite the small sample sizes.

$$V_{85} = 6.45 + 0.875 \cdot SL - 1.56 \cdot HV + 2.10 \cdot TL + 0.72 \cdot ln(LS) \qquad \rho^2 = 0.699 \tag{1}$$

$$V_{85} = 42.58 + 0.289 \cdot SL - 0.480 \cdot HV + 2.08 \cdot L + 7.45 \cdot TL + 1.64 \cdot ln(LS) \qquad \rho^2 = 0.926 \tag{2}$$

Circular horizontal curves on rural two-lane highways in Nebraska with posted speeds of 88, 96 and 104 km/h were investigated (Schurr et al., 2002) in 40 study sites to determine the relationship between design, operating and posted speeds. The authors found that as the posted speed increases mean speed increases; operating speed on approach curve (V_{85app}) is assumed to have an obvious relationship with posted speed (V_p) and average daily traffic (T_{ADT}):

$$V_{85app} = 70.2 + 0.434 \cdot V_p - 0.001307 \cdot T_{ADT} \qquad \rho^2 = 0.910 \tag{3}$$

Fitzpatrick et al. (2003) noticed that is a common practice setting speed limits (SL) at the 85th percentile of operating speeds (V_{85}). There is a suspicion however that operating and design speeds are often not in agreement. Posting of speed limits based on operating speeds that are inconsistent with design speed can create potential safety problems. Speed limits have been observed to be posted that are higher than the design speed which may also have a safety impact. Therefore, the authors found the next model for tangent sections:

$$V_{85} = 7.675 + 0.980 \cdot SL \qquad \rho^2 = 0.904 \tag{4}$$

A study (Stamtiadis and Gong, 2007a) was performed to examine the relationship among design speeds, operating speeds and speed limits and develop guidelines for selecting the appropriate speeds to minimize any existing discrepancies along these speeds. Roadway sections were selected throughout Kentucky based on the relationship between design speed and posted speed limit and on the number of lanes. The relationship between operating speed and posted speed limit showed a uniform pattern (V_{85} = operating speed, DS = design speed, LC = length of curve, DL = difference between design speed and speed limit, R = radius of curvature):

$$V_{85} = 26.903 + 0.495 \cdot DS + 0.003 \cdot LC - 0.437 \cdot DL - 1633.64 \cdot \frac{1}{R} \qquad \rho^2 = 0.537 \tag{5}$$

In general, these two speed metrics were different and the posted speed limit was lower than the 85th operating speeds. This was true for all groups considered except those where the design speed was lower than the posted speed limit. For those sections, the two speed metrics were not statistically significant. This may indicate that when posted speed limits were higher than design speeds, drivers operated based not on design speed but on posted speed limits. There has been a significant amount of research on the topic of differential speed limits for heavy trucks and automobiles on rural interstate highways; however, the results and conclusions are often conflicting or do not provide definitive conclusions. One of the reasons for the inconsistency of the results is that the research does not address the separate distributions of truck and automobile speeds (Johnson and Pawar, 2007). To determine the attitudes of drivers towards speed limits and understand their behavior, a survey of Greek drivers was undertaken in three roadway environments (Psarianos et al., 2007). The findings from this survey indicate that, in general, drivers do not observe the posted speed limits and feel that they can determine when they can travel at higher or lower speeds. Drivers also feel that the posted speed limits can be exceeded at certain situations and they believe that a range of 10 km/h is an acceptable value. The results of the survey indicate that the roadway environment plays a more important role than the posted speed limit in selecting the appropriate operating speed. This leads to the basic conclusion that often times posted speed limits are placed without the proper considerations and are implemented due to a variety of reasons often unrelated to the roadway environment (Stamatiadis and Gong, 2007b). An Italian research demonstrated that the only simple apposition of a speed limit is not often able to guarantee a good reduction of drivers' speed in safety (Marchionna and Perco, 2006). Also new Italian standards will introduce the practice to set speed limits at the 85th percentile of operating speeds (Ministero delle Infrastrutture e dei Trasporti, 2006).

Given these issues, an experimental investigation was carried out that to examine the relationship between operating speeds and speed limits, and develop models for selecting the appropriate speeds to minimize discrepancies between them.

2. Speed data

2.1. Data collection

For the purpose of this research (Dell'Acqua et al., 2007), we used three traffic counters "KV Laser" made by SODI Scientifica. The operation feature of these devices is endowed with two photocells. It is based on the issue and the receipt of a laser couple beams perpendicularly direct to the road axis. The laser beams are issued to low-power (class 1) and, therefore, harmless for the vehicles occupants. The vehicle speed is inferred by the passage of the vehicle from the first photocell to the second one. The measurer is lodged in fixed posting on an easel or (where possible) in the cabin of a car parked on the margins of the roadway or inside a box in order to protect it from the drivers sight, not to condition its behavior.

Fig. 2.
Traffic counters

The instrument has been fed by a battery (accumulator to the lead) to guarantee the autonomy of its operation, but the low consumption would also have allowed to use the endowments of the support vehicle. The tool is endowed with a hard memory to record data; then all the information can be transferred with the devoted software, on a personal computer through a serial cable. To every vehicular passage the devices have recorded:
- *time* (date, hour, minutes, seconds);
- *vehicle speed* (in km/h);
- *length of vehicle* (in meters);
- *traveling direction* (binary variable: "direction 0" and "direction 1").

The available mass storage has allowed managing an elevated number of transits for long temporal intervals. In the transfer of the data some light anomalies of the system of relief have been managed, relative, for instance, to the case of passages outdistanced less than 0.5 seconds (vehicles traveling in opposite directions that simultaneously pass in front of the laser measurer). Besides the axis of the laser beams couple were projected on surfaces with low reflecting ability and sometimes the axles of the vehicle were not perpendicular to the axis of the roadway. They are other anomalies recorded. The first objective is the debugging of correlations between the operating speeds (V_{85}) and the geometric features of the roads. The first group of investigations 2003-04 observed for twelve hours one or two stations belonging to 63 roads, for a total of 85 stations and over thousand hours of survey. We classified the infrastructures in operation of the vehicle speeds and of the traffic volumes. The purpose is to select the ones characterized by the more elevated operating speeds (73-99 Km/h) and by the lower vehicular flow ($Q < 400$ vehicles/h). The data were collected on 6 highways belonging to road network of the Province of Salerno: SP52, SS166, SS426 in "Vallo di Diano" and SP30b, SP262, SP312 in "Piana del Sele".

2.2. Data analysis

We preventively filtered the data for getting a sample of transits really representative of the passages of cars in freeflow conditions, because the environmental speed is more possible on "faster" layouts and operating speeds is necessarily referred to low traffic conditions. So we enucleated the only transits of vehicles with:
- *length* between 2.5 and 9.0 meters, like to cars for private use;
- *gap* superior to 5 seconds from the preceding vehicle (absence of loan conditioning among the vehicles).

The roads have been qualified with:
- V_{85} (index of the probability of attainment of the environmental speeds V_{env});
- *traffic flow* related to the whole period of survey (12 hours);
- the *hourly volumes* are almost always inferior resulted to the value of threshold individualizes the free flow conditions.

2.3. Statistical analysis

A basic assumption for speeds is that the observations obtained from a normal distribution. This assumption needs to be verified for each site. Moreover, for the sites where few spot speeds were obtained, it was more important to check the normality before using the collected data in the analysis. Insufficient spot speed samples cannot represent the real population, and therefore they will likely produce meaningless results. The normality check procedure includes the Kolmogorov-Smirnov test and probability plotting. It is a non-parametric test for goodness-of-fit. It can be used to test whether the distribution of a sample matches a specific distribution, in this case the normal distribution (Figure 3). If the p-value of the Kolmogorov-Smirnov test is less than the significance level considered, the distribution of the sample is not normal at the significance level. If the p-value is greater than the significance level, a probability plot should be used to determine whether the distribution of a sample is normal or not. The software of Statistical Package for the Social Sciences (SPSS) was used for the Kolmogorov-Smirnov test. In this study, both regression methods were used to develop a prediction model for operating speed of passenger vehicles and speed limit.

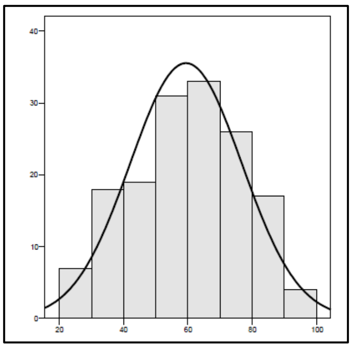


Fig. 3.
Speed frequency on highway SP312 with SPL=50 Km/h

2.4. Results

In this section the relationship among speeds, speed limits and other variables is described.
The use of the speed limit is one of the possible measures for the reduction of the driver speed. This measure has the meaningful advantage to be extremely economic and quick implementation. Nevertheless, the posted speed limit can be not effectiveness to reduce the speed, frustrating the possible safety analysis. There is the possibility to apply a limitation of the speed through opportune signals, because it is not possible to modify operating speed profile intervening on geometric layout (or using other measures that can induce the driver to reduce the speed). Nevertheless, this measure is not always able to get the anticipated effect, particularly when speed limit does not correspond to the speed that driver holds acceptable on the perceived risk. Unfortunately, the limitation of speed is used often in an unsuitable way, more to avoid responsibility for the road administration whether to furnish a useful information to driver. The consequence is that there is a diffused habit to the speed limits and the ones correctly installed do not become effectiveness. To verify the correspondence among the 85th percentile speed and the speed limit the research group surveyed 32 tangents (72 m ≤ L ≤ 4787 m; mean length: L = 2130 m; standard deviation: 1789.8 m) and 15 curves (55 m ≤ R ≤ 280 m; mean radius: R = 149 m; standard deviation: 83.8 m) belonging to 6 double direction one carriageway rural roads on level or hilly terrain, characterized by road width between 5.00 m and 10.00 m (Dell'Acqua et al., 2007). The data collection was held by using traffic counters with infrared rays type active. It was done hiding the equipment and the operator to the traffic to avoid that speeds could be influenced by their presence. The relieves have been conducted in the daytime, with good visibility and dry paving conditions. We surveyed isolated passenger cars (gap 5 seconds) for every study site. The posted speed limit in 47 sites was constituted by the special vertical signal. In the other 7 cases we referred to the generalized speed limit for the local rural roads foreseen by the Italian Road Legislation N.C.d.S. (90 km/h). In Figure 4.a you can see the operating speed on curves and in Figure 4.b the operating speed on tangents in function of the posted speed limit. These two plots clearly show operating speeds are generally superior to the speed limit.

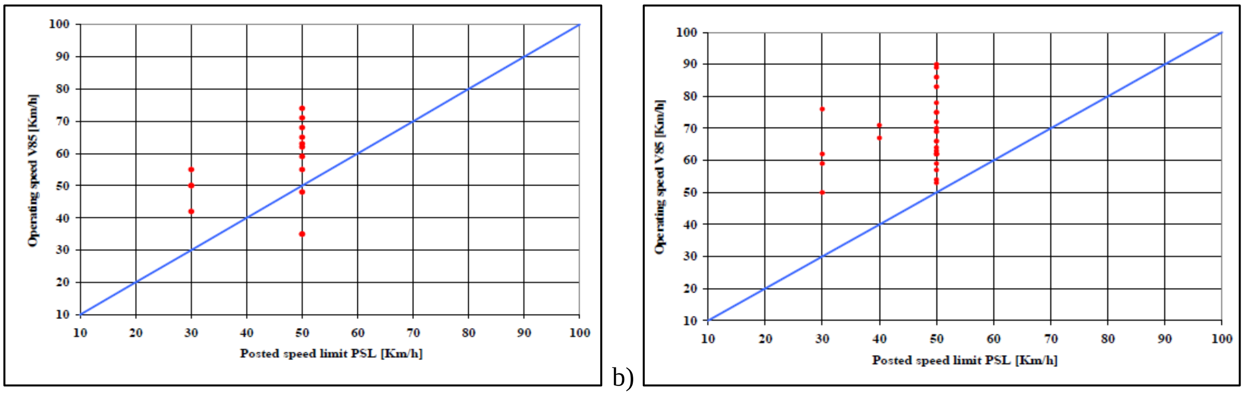


Fig. 4.
a) Operating speed V_{85} versus posted speed limit PSL on curves; b) on tangents

The writing research group calculated $\Delta V_{P,T} = V_{85T} - PSL$ for posted speed limit on tangent, $\Delta V_{P,C} = V_{85C} - PSL$, for posted speed limit on curve and $\Delta V_G = V_{env} - GSL$ for generalized speed limit. Where:
- $\Delta V_{P,T}$ is the difference between operating speed on tangent V_{85T} and posted speed limit *PSL*;
- $\Delta V_{P,C}$ is the difference between operating speed on curve V_{85C} and posted speed limit *PSL*;
- ΔV_G is the difference between environmental speed on homogeneous section V_{env} and generalized speed limit *GSL*.

The environmental speed represent the speed which drivers go when they are conditioned only by the geometry of the single road elements and is defined by the Australian Standards as the maximum speed of the 85th percentile of the speeds surveyed on longer tangents or on curves with a very large radius belonging to a homogenous road section. The geometric feature of every homogenous highway section were characterized with the ratio between the sum of the deflection angles (γi) of successive elements of the horizontal alignment and the length of the homogeneous road section. This parameter is the Curvature Change Rate C.C.R. = Σi|γi|/d [gon/km]. The homogeneous sections are identified by various constant slope interpolating the overall curvature.

Table 1
Surveyed environmental speeds

	Highway	*C.C.R.* [gon/km]	V_{env} [km/h]
1	SS 166	589.264	73
2	SS 426	235.793	83
3	SP 52	159.277	86
4	SP 312	47.156	88
5	SS 426	63.288	96
6	SP 30b	9.601	97
7	SP 262	9.916	103

Table II shows the Mean differences of speed observed, the 85th percentile and the standard deviation SD.

Table 2
Average differences of speeds

	$V_{P,T}$ [km/h]	$V_{P,C}$ [km/h]	V_G [km/h]
Mean	22.34	10.80	-0.57
85^{th}	34.05	20.90	7.60
SD	11.16	12.70	10.08

The average differences of speed observed is 11 km/h and standard deviation is 12.7 km/h on curves; 22 km/h and 11.2 km/h on tangents; -0.57 km/h and 10.1 km/h on homogeneous sections. It is a meaningful value in fact it underlines is not possible to really confuse the speed limit with the practiced speed like in a road safety analysis. The histograms of the distribution of speeds, the posted speed limit, the operating speed and the mean speed are plotted in figures 5, 6 and 7 for some measurement stations on tangents and curves with posted speed limits of 30 and 50 km/h.

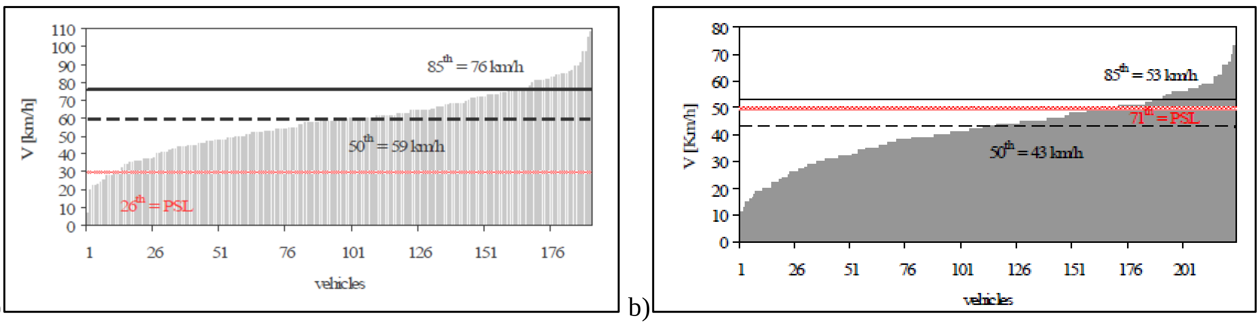


Fig. 5.
a) SS426 Tangent (L= 502 m); b) SP312 Tangent (L= 2908 m)

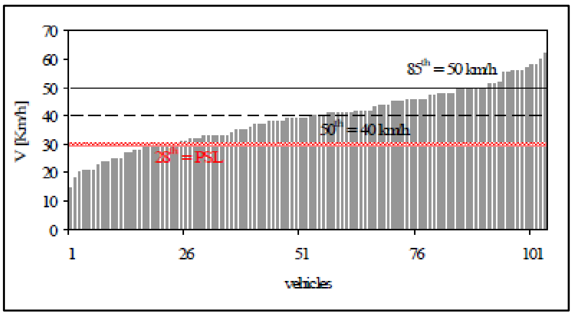


Fig. 6.
SS166 Tangent (L= 76 m)

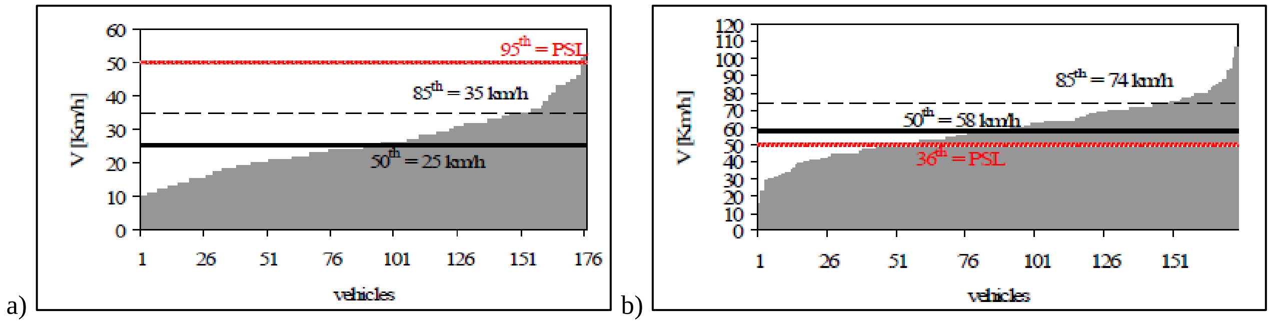


Fig. 7.
a) SP312 Curve (R= 100 m); b) SS426 Curve (R= 240 m)

The database is formed by two groups of study sites for evaluating the effects of the posted speed limits in drivers' behaviour: in the former (32 tangents and 15 curves) there are vertical signals; in the latter (7 homogeneous sections) the generalized speed limit of the highway is considered. We observed the speed differences: $(\Delta V_{P,T})_{max}$ = 46 km/h for tangents with posted speed limit; $(\Delta V_{P,C})_{max}$ = 25 km/h for curve with posted speed limit and $(\Delta V_{G})_{max}$ = 13 km/h for the homogeneous sections with generalized speed limit (Dell'Acqua et al., 2007). This last result depends on the geometric features of roads layout, that meaningfully conditions the driver speed behaviour. As a result the ΔV is greater where the signal is because it is normally inferior to the generalized limit. These results are not generally valid, because the sample is a little numerous. The data are not homogeneous, in fact operating speed is divided among the different limits for the stations with vertical speed limit signal, and instead it refers on generalized limit for the "faster" stations on homogeneous sections. Finally we notice that in both cases the difference of observed values of speeds is greater where the signal is located. Particularly on tangents the geometric features have less influence on the speed in comparison to the curves. It underlines that the posted speed limit is not respected: the mean operating speed on tangents is 70 km/h (49 km/h $\leq V_{85} \leq$ 90 km/h, standard deviation: 10.8 km/h); the mean operating speed on curves is 57 km/h (35 km/h $\leq V_{85} \leq$ 74 km/h, standard deviation: 11.9 km/h); the mean operating speed on homogeneous sections is 92 km/h (83 km/h $\leq V_{85} \leq$ 103 km/h, standard deviation: 7.7 km/h). As a result the speeds are greater where the signal is not, because it is normally inferior to the generalized limit (Dell'Acqua et al., 2007).

3. Conclusions

The existing rural road network is much extended and a wide part of it is represented by one carriageway double direction rural roads in Italy. It requires interventions of adjustment to improve the quality of the offered service and the safety mobility management (Dell'Acqua and Russo, 2011b; Dell'Acqua et al., 2005). These interventions obviously have effected following a sustainable economic approach and it is necessary to make sure that the allocated resource achieves the maximum possible benefits. To guarantee this objective, it is necessary to support the planning of road safety interventions with an analysis able to verify the correctness of the proposals of adjustment by using the most opportune tools (Abbondati et al., 2016; De Luca and Dell'Acqua, 2012). One of the most important tools of this analysis is the diagram of the 85th percentile speed. It allows effecting numerous important verifications because it is able to effectively represent the real speed held by the drivers. The measures that allow to reduce this speed to adjust it to the demands of the intervention of adjustment of roads are different, but everyone characterized by very varying ratio costs/benefits. There is surely the posted speed limit among the most economic feed-forward. To verify the effectiveness of this measure, the writers observed operating speed on 51 study sites and compared the results with the posted speed limit. The analyses clearly suggest that the 85th percentile speed is meaningfully always superior to the posted speed limit. There is also an exception: geometric characteristics influence some sites more than the speed limit. Therefore it should be accompanied to other specific measures, in the cases in which the necessity of this reduction is tightly tied to the safety of the mobility.

Acknowledgements

This study was financed by the University of Napoli Federico II as part of the Agreement of Cooperation with the University of Belgrade (Serbia) - Resolution CdAUniNa September 21, 2012.

References

Abbondati, F. et al. 2016. Linear scheduling analysis toolkit for road and airports construction projects, *ARPN Journal of Engineering and Applied Sciences*, 11(11): 6863-6874.

Alberico, I. et al. 2012. Mapping the vulnerability for evacuation of the CampiFlegrei territorial system in case of a volcanic unrest, *Natural Hazards*, 64(2): 1823-1854.

Aljanahi, A.A.M. et al. 1999. Speed, speed limits and road traffic accidents under free flow conditions, *Accident Analysis and Prevention*, 31: 161-168.

Bella, F. 2005. The evaluation of Design Consistency: Predicting Models of Operating Speed on Three-Dimensional Alignment from Tests on Driving Simulator. In *3rd International Symposium on Highway Geometric Design*, Chicago, U.S.A.

Benedetto, A. et al. 2004. A new effective approach to accidents prediction to improve roads' design and rehabilitation, *Advances in Transportation Studies an international Journal*, Section A 4, Vol. IV, November.

Capaldo, F.S. 2004a. A behavioral model of flows on roundabouts. In *Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering*, 301-306.

Capaldo, F.S. 2004b. A behavioural driver model for two lane roads. In *Proceedings of 4th International Conference on Traffic and Transportation Studies*, 803-810.

Capaldo, F.S. 2012a. Passing Maneuver: Survey, Some Models and Simulations. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 589-597.

Capaldo, F.S. 2012b. Driver Eye Height: Experimental Determination and Implications on Sight Distances. In *Proceedings in the 8th International Conference on Traffic and Transportation Studies (ICTTS)*, 375-383.

Capaldo, F.S. 2012c. Road Sight Design and Driver Eye Height: Experimental Measures. In *Proceedings of the 5th SIIV International Congress on Sustainability of Road Infrastructure, Procedia Social and Behavioral Sciences*, 732-741.

Capaldo, F.S.; Grossi, R. 1996. Automatic system for the definition of the setting rules for speed diagrams. In *Proceedings of the International Conference on Applications of Advanced Technologies in Transportation Engineering*, 193-197.

Capaldo, F.S.; Biggiero, L. 2012. Some Surveys in order to Static Traffic Light Coordination. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 313-320.

Capaldo, F.S.; Nasti, G. 2012. Analysis of Road Safety: Three Levels of Investigation. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE)*, 185-192.

Capaldo, F.S.; Biggiero, L. 2014. Experimental Survey and Modeling for the Driver Behavior in Vehicle Platoons. In *Proceedings of the 9th International Conference on Traffic and Transportation Studies (ICTTS)*, 279-288.

Capaldo, F.S. et al. 2000a. Accidents and geometric characteristics of road layout: Some quantitative evaluations. In *Proceedings of the 2nd International Conference on Traffic and Transportation Studies (ICTTS 2000)*, 80-87.

Capaldo, F.S. et al. 2000b. Airport capacity according to ICAO rules: Some quantitative evaluations. In *Proceedings 2nd International Conference on Traffic and Transportation Studies (ICTTS 2000)*, 803-810.

Capaldo, F.S. et al. 2012. Passing Maneuver: Models, Surveys and Simulation. In *Proceedings in the 8th International Conference on Traffic and Transportation Studies (ICTTS)*, 790-798.

Čavka, I. et al. 2014. Learning from errors–case study of an aircraft accident. In *Proceedings of the International Conference on Traffic and Transport Engineering*, 444-450.

Chowdhury, M.A. et al. 1991. Analysis of Advisory Speed Setting Criteria, *Public Roads*, 55(3): 65-71.

Čokorilo, O. et al. 2014. Aircraft safety analysis using clustering algorithms, *Journal of Risk Research*, 17(10): 1325-1340.

Dell'Acqua, G. 2011a. Reducing Traffic Injuries Resulting from Excess Speed Low-Cost Gateway Treatments in Italy, *Transportation Research Record*, 2203: 94-99.

Dell'Acqua, G. 2011b. European speed environment model for highway design-consistency, *Modern Applied Science*, 6(9): 1-10.

Dell'Acqua, G. 2015. Modeling Driver Behavior by using the Speed Environment for Two-Lane Rural Roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2472: 83-90.

Dell'Acqua, G.; Lamberti, R. 2003. A Linear Scheduling Model to Plan Road Works. In *Proceedings of the XXII° World Road Congress*, CD-ROM.

Dell'Acqua, G.; Russo, F. 2010. Speed factors on low-volume roads for horizontal curves and tangents, *The Baltic Journal of Road and Bridge Engineering*, 5(2): 89-97.

Dell'Acqua, G.; Russo, F. 2011a. Safety Performance Functions for Low-Volume Roads, *The Baltic Journal of Road and Bridge Engineering*, 6(4): 225-234.

Dell'Acqua, G.; Russo, F. 2011b. Road Performance Evaluation Using Geometric Consistency and Pavement Distress Data, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 194-202.

Dell'Acqua, G. et al. 2005. Computer Based Linear Scheduling Application for Highway Construction Planning. In *Proceedings of the III° SIIV Congress*, Bari, Italy. CD-ROM.

Dell'Acqua, G. et al. 2007. Field Studies on Posted Speed Limits. In *Proceedings of the International Conference Road Safety and Simulation (RSS)*, 7-8-9th November, Rome, Italy.

Dell'Acqua, G. et al. 2011a. Road safety knowledge-based decision support system, *Procedia Social and Behavioral Sciences*, 20: 973-983.

Dell'Acqua, G. et al. 2011b. Motorway speed management in southern Italy, *Procedia Social and Behavioral Sciences*, 20: 49-58.

Dell'Acqua, G. et al. 2011c. Indirect Skid Resistance Measurement for Porous Asphalt Pavement Management, *Transportation Research Record: Journal of the Transportation Research Board*, 2205: 147-154.

Dell'Acqua, G. et al. 2011d. Descriptors in Scenic Highway Analysis: a Test Study along Italian Road Corridors, *International Journal for Traffic and Transport Engineering*, 1(2): 73-88.

Dell'Acqua, G. et al. 2012a. Procedure for Making Paving Decisions with Cluster and Multicriteria Analysis, *Transportation Research Record: Journal of the Transportation Research Board*, 2282: 57-66.

Dell'Acqua, G. et al. 2012b. Mix Design with Low Bearing Capacity Materials, *The Baltic Journal of Road and Bridge Engineering*, 7(3): 204-211.

Dell'Acqua, G. et al. 2013a. Safety Data Analysis to Evaluate Highway Alignment Consistency, *Transportation Research Record: Journal of the Transportation Research Board*, 2349: 121-128.

Dell'Acqua, G. et al. 2013b. Risk-type density diagrams by crash type on two-lane rural roads, *Journal of Risk Research*, 16(10): 1297-1314.

Dell'Acqua, G. et al. 2013c. Validation procedure for predictive functions of driver behaviour on two-lane rural roads, *European Transport*, (53) paper 10.

Dell'Acqua, G. et al. 2016. The impact of vehicle movement on exploitation parameters of roads and runways: a short review of the special issue, *Transport*, 31(2): 127-132.

De Luca, M. 2015. A Comparison Between Prediction Power of Artificial Neural Networks and Multivariate Analysis in Road Safety Management, *Transport*, 1-7.

De Luca, M.; Dell'Acqua, G. 2012. Freeway safety management: Case studies in Italy, *Transport*, 27(3): 320-326.

De Luca, M.; Dell'Acqua, G. 2014a. Runway surface friction characteristics assessment for LameziaTerme airfield pavement management system, *Journal of Air Transport Management*, 34: 1-5.

De Luca, M.; Dell'Acqua, G. 2014b. Calibrating the passenger car equivalent on Italian two line highways: A case study, *Transport*, 29(4): 449-456.

De Luca, M. et al. 2011. Before-after freeway accident analysis using Cluster algorithms, *Procedia Social and Behavioral Sciences*, 20: 723-731.

De Luca, M. et al. 2015. Pavement Friction Decay: Preliminary Study in Lamezia Terme International Airport, Italy. In *Proceedings of the Transportation Research Board 94th Annual Meeting*, 15-0126.

De Luca, M. et al. 2016a. Field measurements on runway friction decay related to rubber deposits, *Transport*, 31(2): 177-182.

De Luca, M. et al. 2016b. Preliminary study on runway pavement friction decay using data mining, *Transportation Research Procedia*, 14: 3751-3670.

Discetti, P. et al. 2011. Models of operating speeds for low-volume roads, *Transportation Research Record: Journal of the Transportation Research Board*, 2203: 219-225.

Esposito, T. et al. 2011. Speed prediction models for sustainable road safety management, *Procedia Social and Behavioral Sciences*, 20: 568-576.

Esposito, T. et al. 2012. Operating speed prediction models for sustainable road safety management. In *Proceedings of the 14th Euro Working Group on Transportation & 26th Mini Euro Conference & 1st European Scientific Conference on Air Transport*, 712-721.

Fambro, D.B. et al. 1997. Determination of Stopping Sight Distances. *NCHRP Report 400*, Transportation Research Board, Washington, DC.

Fitzpatrick, K. et al. 1995. Compatibility of Design Speed, Operating Speed, and Posted Speed. *Final Report FHWA/TX-95/1465-2F*. Texas Department of Transportation, College Station, TX, October.

Fitzpatrick, K. et al. 1999. Design Factors That Affect Driver Speed on Suburban Arterials. *Report FHWA/TX-00/1769-3*. Texas Transportation Institute, College Station, TX, August.

Fitzpatrick, K. et al. 2000. Speed Prediction for Two-Lane Rural Highways. *Report FHWA-RD-99-171*. Federal Highway Administration, Washington, DC.

Fitzpatrick, K. et al. 2003. Design speed, operating speed, and posted speed limit practice. *NCHRP 504*, Transportation Research Board, Washington, DC.

Haglund, M.; Aberg, L. 2000. Speed choice in relation to speed limit and influences from other drivers, *Transportation Research Part F*, 3: 39-51.

ITE Technical Committee 97-12, Parma, K.. chair 2001. Survey of Speed Zoning Practices. *ITE Informational Report*. Institute of Transportation Engineers, Washington, DC.

Johnson, S.L.; Pawar, N. 2007. Analysis of heavy truck and automobile speed distributions for uniform and differential speed limit configurations on rural interstate highways. In *Transportation Research Board Annual Meeting Proceedings*.

Krammes, R.A. et al. 1994. Horizontal Alignment Design Consistency for Rural Two-Lane Highways. *Research Report FHWA-RD-94-034*. Federal Highway Administration, Washington, DC.

Lamberti, R. et al. 2010. Visual impact assessment for infrastructure design, *Large Structures and Infrastructures for Environmentally Constrained and Urbanised Areas*: 668-669.

Marchionna, A.; Perco, P. 2006. Potenzialità offerte dal diagramma delle velocità operative nella definizione degli interventi di adeguamento delle strade esistenti. In *16th National SIIV Congress Proceedings*, Cosenza, Italy.

Mauro, R. et al. 2013. Using a k-means clustering algorithm to examine patterns of vehicle crashes in before-after analysis, *Modern Applied Science*, 7(10): 11-19.

Ministero delle Infrastrutture e dei Trasporti 2006. II° direttiva *Sulla corretta ed uniforme applicazione delle norme del codice della strada in materia di segnaletica e criteri per l'installazione e la manutenzione*. Draft, Italy.

Parker, M.R.Jr. 1985. Synthesis of Speed Zoning Practices. *Publication No. FHWA-RD-85-096*. Federal Highway Administration, Washington, DC, July.

Parker, M.R.Jr. 1992. Comparison of Speed Zoning Procedures and Their Effectiveness. *Final Report, prepared for the Michigan Department of Transportation*. Lansing, Michigan, September.

Parker, M.R.Jr. 1997. Effects of Raising and Lowering Speed Limits on Selected Roadway Sections, Final Report. *Publication No. FHWA-RD-92-084*. Federal Highway Administration, Washington, DC, January.

Psarianos, B. et al. 2007. Attitudes of Greek drivers towards posted speed limits. In *4th International SIIV Congress Proceedings*, Palermo, Italy.

Russo, F. et al. 2013. A statistical look at gender and age differences as related to the injury crash type on low-volume roads, *WIT Transactions on the Built Environment*, 134: 213-224.

Russo, F. et al. 2014a. Road Safety from the Perspective of Driver Gender and Age as Related to the Injury Crash Frequency and Road Scenario, *Traffic Injury Prevention*, 15(1): 25-33.

Russo, F. et al. 2014b. Consistent approach to predictive modeling and countermeasure determination by crash type for low-volume roads, *The Baltic Journal of Road and Bridge Engineering*, 9(2): 77-87.

Russo, F. et al. 2014c. Assessing Transferability of Highway Safety Manual Crash Prediction Models to Data from Italy, *Transportation Research Record: Journal of the Transportation Research Board*, 2433: 129-135.

Russo, F. et al. 2015. Driver Speed Behavior on Circular Curves of Undivided Two-Lane Rural Roads. Serbian and Italian Case Studies, *Transportation Research Record: Journal of the Transportation Research Board*, 2472: 117-128.

Russo, F. et al. 2016a. Safety performance functions for crash severity on undivided rural roads, *Accident Analysis and Prevention*, 93: 75-91.

Russo, F. et al. 2016b. Operating speed as a key factor in studying the driver behavior in a rural context, *Transport*, 31(2): 260-270.

Schurr, K.S. et al. 2002. Relationship Between Design, Operating and Posted Speeds on Horizontal Curves on Rural Two-Lane Highways in Nebraska. In *Transportation Research Board Annual Meeting Proceedings*.

Stamtiadis, N.; Gong, H. 2007a. Analysis of inconsistencies related to design speed, operating speed and posted speed limit. In *4th International SIIV Congress Proceedings*, Palermo, Italy.

Stamatiadis, N.; Gong, H. 2007b. Analysis of Inconsistencies Related to Design Speed, Operating Speed, and Speed Limits. Kentucky Transportation Research Center *Report KTC-06-12*, College of Engineering, University of Kentucky, Lexington, KY, March.

Zilioniene, D. et al. 2013. Evaluation of Climatic Factors Based on the Mechanistic-Empirical Pavement Design Guide, *The Baltic Journal of Road and Bridge Engineering*, 8(3): 158-165.

SESSION 13: SUSTAINABLE TRANSPORT

HOW TO AVOID ARBITRARY DECISIONS? – ACTUAL VS. TARGET DECISION MAKING

Johannes Kehrer[1]
[1] *TU Vienna, Institute of Transportation, Research Center of Railway Engineering, Traffic Economics and Ropeways, Karlspatz 13/230-2, A-1140 Wien, Austria*

Abstract: Selecting the proper transport system for implementation in urban public transport networks is a complex field of decision-making. In order to achieve rational decision-making, different options have to be compared by uniform decision criteria. This paper gives a brief overview of available transport systems and their characteristics. Subsequently, decision criteria, which are meant to be taken into account in the decision making process are identified. The presented transport systems are investigated for their performance regarding these criteria. Furthermore, the ideal decision making process is defined and tools for comparing different solution alternatives, whilst taking the previously defined criteria into account are investigated. These items are discussed, based on literature review and expert interviews on real and ongoing decision-making processes. The results show that there are many decision criteria that affect third parties who are not directly involved in the decision-making process. These are known as external effects and these criteria are often non-monetary parameters. That is why multi criteria analysis turns out to be the most suitable for comparing solution alternatives since they are not dependent on solely monetary values. A comparison between target and actual decision-making processes shows, that in reality political preferences of decision makers divert actual processes from the "ideal" decision-making process. Therefore the ideal decision-making process is defined in theory and is compared to actual decision making processes, based on two case studies in Austria. A comparison between target and actual decision-making, a discussion of the results and an answer to the posed research question conclude the paper. Finally, an outlook on future questions raised during the work on the paper is given.

Keywords: multiple criteria decision-making, comparison tools, decision criteria for public transport modal choice, impact analysis, benefit analysis, cost-impact analysis, cost-benefit analysis, lifecycle cost analysis, multi criteria analysis.

1. Introduction

Conurbations in central Europe have been growing constantly over the last decades which has led to higher traffic volumes within those metropolitan areas. In order to cope with this increase in traffic volumes, public transportation networks have been extended and improved. Especially the central areas of conurbations have a high building density and organically developed structures which strictly constrain the space available for transportation matters. Therefore, it is essential to find the proper transport system to meet these constraints. Furthermore, aspects like emissions of different kinds as well as efficient building and operation costs have to be taken into account.
This paper focusses on the entire decision making process regarding modal choice for urban transport development. First, the most common transport systems in operation in Europe are selected for further investigation, followed by an overview of key decision criteria. Subsequently the ideal decision making process is defined and the most suitable tool for taking all predefined criteria into account is identified. A key part of this paper is the comparison of actual vs. target decision making in that field. Therefore, two actual decision making processes in Austria, one in Linz and one in Graz, are investigated, based on interviews with involved parties in the process.

2. Transport Systems

Transport Systems can be categorized by different standards. (Vuchic, 2007) identified multiple options for categorizing urban public transport systems, however, the conventional classification , which distinguishes between mixed surface transport (public transport is sharing its way with motorized private transport), accelerated surface transport (level crossings but separation from other transport modes in longitudinal direction) and, rapid transit which is usually entirely independet from other transport modes, is used throughout the paper. Additionally, so-called specialized public transport systems are identified in (Kehrer, 2013). They cannot be classified by conventional standards due to unique constraints. Cablecars, furniculars with its limitations regarding alignment (very steep gradients, but no curves possible) or ferries which can only operate on water surfaces are prime examples for that. Except for cablecars which are getting more and more popular in urban public transport, no specialized public transport system is further regarded in this paper.
Categorized transport modes range from various rail guided systems like trams and light rail systems to heavy rail commuter trains and subways. Conventional bus systems, both as operated in mixed traffic and as stand-alone bus rapid transit systems as well as trolley buses and guided buses are taken into account. The first two columns of Table 1 show the conventional classification of Europe's predominant public transport modes. The list aims to cover all relevant transport systems, with no claim to completeness.

[1] Corresponding author: johannes.kehrer@tuwien.ac.at

3. Decision criteria

In order to holistically compare different transport systems for a selected case, decision criteria that have to been taken into account have to be determined.
Based on literature review all known impacts on their environment caused by public transport systems are named.
First of all parameters have been divided into two groups. Technical constraints as hard factors on the one hand and other decision criteria that should be taken into account in this field of decision making on the other.

3.1. Hard factors: technical constraints

The following key factors have been identified as hard constraints for public transport systems:

- Maximum capacity,
- Average travel speed,
- Ideal distance between stops,
- Maximum longitudinal gradient,
- Minimum curve radius,
- Track width.

In contrast to „soft factors“, a transport system has to meet the given constraints in order to even be taken into consideration for the decision-making process.
Maximum capacity can be seen as the key constraint for a public transport system. (Anderhub, Dorbritz, & Weidmann, 2008) define capacity as *„the maximum number of passengers per direction and per time unit and is the product of a transport unit's holding capacity and track capacity.“* Since ridership is the main premise for implementing a public transport service, the ex-ante estimated demand is likely to already rule out certain transport systems. For example if a sparsely populated area should be accessed by public transport, a subway with its high capacity will most likely not be taken into consideration. Table 1 shows maximum capacities of the investigated transport systems. The diverging values show that some systems will hardly ever directly compete with each other.
Average travel speed and the transport unit's maximum speed are "benchmarks for the quality of traffic flows" according to (Steierwald, Kühne, & Vogt, 2005). A combination of these two parameters, along with maximum capacity and acceleration performance lead to the **ideal distance between two stops**. Although not really a technical constraint, this parameter along with maximum capacity determines the transport function and capability of a transport system.
Apart from the performance indicators described above, geometrical constraints concerning a transport systems alignment apply. The key parameters in this field have been identified in (Kehrer, 2013) as **maximum longitudinal gradient**, **minimum curve radius** and **track width**. In general, bus systems can climb the steepest gradients and have the minimum curve radiuses compared to rail guided systems. Cable cars are an example for how a specialised transport system can cope with the steepest gradients of all investigated systems of up to 100% but can hardly be designed with curves. They can only be implemented at expensive stations where the cabins do not have to be taken off the rope temporarily.

Table 1
Maximum capacities of the investigated transport systems

Classification	transport system	max. holding capacity [Pers/TU]	max. track capacity [TU/h]	maximum capacity [Pers/h]
Mixed surface transport	Bus	40 - 120	60 - 180	2.400 -6.000
	Tram	100 - 500	60 - 120	4.000 - 15.000
Accelerated surface transport	BRT	40 - 150	60 -300	4.000 - 8.000
	LRT	100 - 750	40 - 60	6.000 - 20.000
	Guided Bus Systems	180 - 360	60 -120	10.000 - 18.000
Rapid transit	Subway	140 - 2400	20 - 40	10.000 - 70.000
	Commuter Trains	140 - 2000	10 - 30	8.000- 60.000
Specialized transport systems	Detachable cable car	4 - 38	240 - 500	2.000 - 6.000

Source: (Alshalalfah & Shalaby, 2010) (Vuchic, 2007)

3.2. Soft factors

The so-called "soft factors" are decision criteria that have to be taken into account when choosing a holistic approach in decision making in the field of modal choice. However, these factors are not strict constraints as compared to the "hard

factors" which can be seen as yes/no factors. Soft factors show effects of an eventual decision that have to be weighed and compared to other soft factors.
The following groups of soft factors have been identified as relevant decision criteria:

- Operational factors,
- Economic factors,
- Effects on the urban structure,
- External effects,
- Effects on ridership.

Operational factors in general, focus on the operator's point of view. However, these factors ultimately result in effects on ridership. (Steierwald, Kühne, & Vogt, 2005) name *reliability*, *flexibility* and *safety* as main performance indicators for operational matters. A transport system's performance on these factors cannot be quantified and therefore have been rated from „very low" to „very high".
Operational *reliability* primarily means a low breakdown susceptibility, as described by (Deutsch, 2003). However from an operator's point of view, low maintenance systems contribute to operational reliability (Steierwald, Kühne, & Vogt, 2005). Generally speaking, reliability grows with a transport system's growth in independence from other traffic flows. To name an example, cable cars can be seen as very reliable since they hardly ever breakdown and are not influenced by any other mode. However, high wind speeds can lead to a temporary breakdown.
The term *flexibility* unites various aspects that determine a transport system's ability to react to external influences on operations. That includes abilities like running around other vehicles, overtaking other vehicles, demand-driven disposition and flexible line layout. Table 2 shows an evaluation of the chosen transport systems regarding flexibility.
Similar to *reliability*, the *safety* of a transport system can directly be linked to its independence from other traffic flows since (Stoop & Thissen, 1997) describe accidents as combinations of both a system's complexity and its number of interfaces.
Economic factors can be divided into initial costs (building and planning), operational costs and external economic effects. Although general benchmarks for initial and operational costs of transport systems have been found in literature, they have to be carefully estimated for every given case.
External economic effects can be divided into direct effects and indirect effects as done by (Huang & Xia, 2011). Direct effects include jobs and orders directly caused by the implementation of a transport system. Since building projects of greater volumes have to be procured by an EU-wide tendering process, it is hardly possible to anticipate how many of the jobs actually benefit the local economy. However, direct effects can be set equal to the amount of money spent for implementation.
Indirect effects include the effect of the implementation of a public transport system on the surrounding areas, i.e. property values. Multiple studies have shown, that rail guided transport leads to a higher boost for property values with access to the transport system than bus transport as shown by (Pagliara & Papa, 2011). Heavy rail systems also lead to higher increases in property values than light rail systems, according to (Ibeas, Cordera, Dell'Olio, Coppola, & Dominguez, 2012).

Table 2
Aspects of flexibility

Classification	transport system	Running around	Overtaking	demand-driven disposition	flexible line-layout	overall flexibility
Mixed surface transport	Bus	very high	very high	very high	very high	**very high**
	Tram	average	low	high	average	**average**
Accelerated surface transport	BRT	gut	high	high	average	**high**
	LRT	low	low	high	average	**average**
	Guided Bus Systems					**average**
Rapid transit	Subway	niedrig	niedrig	high	very low	**low**
	Commuter Trains	average	average	high	average	**average**
Specialized transport systems	Detachable cable car	low	low	very high	very low	**average**

Source: (Kehrer, 2013)

The principle for urban planning of European cities is described as a combination of four targets: *high density*, *mix of uses*, *public spaces* and *ecologically promoted spaces* by (Steierwald, Kühne, & Vogt, 2005). **Effects on the urban structure** by transport systems affect those targets. Since it is very space-efficient, public transport is beneficial for *public spaces* and *ecologically promoted spaces*. Due to increased accessibility and therefore shorter trips for inhabitants, the implementation of public transport systems usually both lead to an increase in *density* and the *mix of uses* as described by (Ibeas, Cordera, Dell'Olio, Coppola, & Dominguez, 2012) and (Steierwald, Kühne, & Vogt, 2005).

External effects describe all effects on nature or third parties that cannot be directly translated into a monetary value (Zhibin, Wei, Xuedong, Chen, & Yaotian, 2010). These effects include greenhouse gas emissions, other gas emissions, particulate matter emissions, noise emissions, vibrations caused and energy efficiency of the transport system. It is essential to take these effects into account and weigh them accordingly in the decision making process. However, these effects are not further described at this point.

Effects on ridership include time savings, acceptance and barrier free accessibility. Time savings are usually the key argument for promoting new public transport systems and are therefore the highest valued benefit (Steierwald, Kühne, & Vogt, 2005). This benefit needs to be put in proper perspective however, since it is a well-known phenomenon that greater velocities lead to greater trip lengths instead of time savings on a macroscopic level and in the long run (Rollinger, Emberger, & Brezina, 2009). Acceptance by ridership has often been observed to depend on the transport system. For example, rail guided transport systems are expected attract more customers than bus systems on the same line (Brezina, 2004). Barrier free accessibility to public transport systems is legally required nowadays. Due to technical innovations, all investigated transport systems may be designed to meet these standards.

Apart from the decision criteria mentioned above, there might be additional influences on the decision making process. Political will for example might lead – due to political considerations or strategies – to a different direction than the other criteria. Certain models for financing infrastructure might also arbitrarily prefer one transport system over another.

4. Ideal decision making

First the ideal decision making process is defined, followed by an evaluation of tools that are best for taking multiple decision criteria into account.

4.1. Process flow

A decision is commonly known as the *choice/selection of one among several options*. (Steierwald, Kühne, & Vogt, 2005) have defined a general ideal decision making process, as illustrated in Fig. 1.

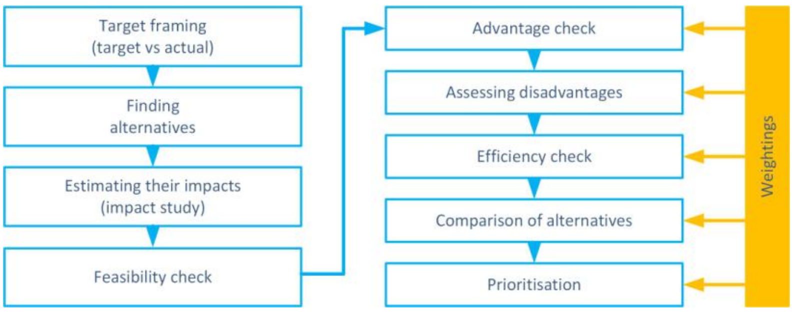


Fig. 1.
The ideal decision making process.
Source: (Steierwald, Kühne, & Vogt, 2005), own illustration

At the very beginning of a decision making process the target must be framed. It can be seen as the definition of a target, based on existing problems or challenges. In the field of public transportation this could be a desired shift from private to public transport, due to overcrowded streets. A target-seeking approach defines the constraints for the future decision making process. However, (De Bruijn & Veeneman, 2009) observed that decision making in the field of modal choice for public transport is mostly target-oriented. For example, decision makers already know, they want to implement a certain transport system and then define their targets. This can be seen as the first, big hindrance for a decision making process solely based on selected criteria.

Finding alternatives can be seen as the creative phase of the process. At this stage, both conventional and innovative approaches should be added to the list. In the field of modal choice this means all public transport systems mentioned above (and maybe even more) should be taken into account.

Estimating their impacts displays the impact of every single alternative. This step has to be carried out very carefully and with common standards, since they are weighed and directly involved in the comparison of alternatives later on.

The feasibility check filters out alternatives that cannot meet the targets defined in the very beginning. For the present field of decision making this may apply for „hard factors“ such as maximum capacity or geometrical constraints.

The advantage check eliminates all alternatives that are not advantageous for reaching the targets. Assessing the disadvantages leads to an elimination of all alternatives with serious disadvantages for the target.

In the efficiency check, disadvantages and advantages of different alternatives are compared in pairs. In the next step, comparison of the remaining alternatives are finally compared in pairs. At the very end of this decision making process, the alternatives are ranked – solely based on their performances in the steps before – and a „winner“ is named.

In the last five steps of the ideal decision making process, weightings are taken into account. Those weightings are subjective. However, criteria taken into account as well as their weightings have to be defined prior to assessing the alternatives‘performances in those fields.
At this stage, „soft factor“-decision criteria as mentioned above have to be assessed for each alternative. It is very important to use common standards and reach the same level of information for all alternatives, since these parameters are weighed and are the key part in the consecutive comparison of alternatives.
Having assessed all information, the comparison of alternatives should rank the alternatives according to their overall performance and finally name a winner.

4.1. Comparing alternatives

The last five steps – as seen in Fig. 1. – are not necessarily separated but can be accomplished by one evaluation method. According to (Hoffmann, 2013), standardised evaluation methods have to meet certain standards such as transparency, reliability of input data, consideration of all significant effects among others. If these standards are secured, a standardised evaluation method is preferable to other approaches.
The following standardised evaluation methods are examined concerning their suitability for modal choice:

- Impact analysis,
- Benefit analysis,
- Cost-impact analysis,
- Cost-benefit analysis,
- Lifecycle cost analysis (LCC),
- Multi criteria analysis.

Although the **impact analysis** is one of the very first steps in the ideal decision making process, it can also be used as the only evaluation method. (Hoffmann, 2013) describes it as an assessment of all effects of a project on its environment. These effects are displayed in a list but are not weighed or compared in a standardised way. This leaves plenty of room for arbitrary interpretation of decision makers. Since effects do not necessarily have to be quantified, external effects and other „soft“ decision criteria can easily be taken into account.
<u>Interpretation:</u> All in all, an impact analysis only leaves room for arbitrary decisions, since criteria and their weightings are not defined earlier in the decision making process.
A **benefit analysis** also just focuses on the effects of a project on its environment and does not take costs into account. In contrast to the impact analysis, a benefit analysis has a complex underlying model to compare alternatives to one another. Decision criteria and weightings are predefined. On that basis, a so called „grade of target achievement“ is calculated for every criteria and later on compared in a matrix. One alternative is finally awarded with the highest grade of target achievement.
<u>Interpretation:</u> The benefit analysis is a standardised method that can very well take into account various decision criteria. Criteria and weightings are selected beforehand in order to avoid arbitrary decisions. However, costs are not yet taken into account, although – especially for infrastructure projects – they are a key criterion.
The **cost-impact analysis** is based on the benefit analysis but also takes the costs of a project into account. The „grade of target achievement“ is finally divided by the project’s costs. It is essential to distribute and discount the costs over the whole operating life. The benefit per year divided by the costs is defined as the cost-benefit-quotient. The alternative with the highest quotient is the preferred one.
<u>Interpretation:</u> The cost benefit analysis can take all decision criteria – including costs – into account. Although external effects do not have to be monetarized in the first place, the comparison with the costs has a similar effect. Therefore, weighting of external effects has to be done carefully.
The **cost-benefit analysis** aims to reach a “complete monetarization of all relevant impacts of a measure (project), both taking costs and positive or negative costs caused by its impact into account.” (Hoffmann, 2013) The result of the cost benefit analysis can be displayed by two parameters. The benefit/cost quotient as an indicator for a projects efficiency on the one hand and the benefit-cost difference as a sign for a measure‘s total yield. Costs are usually discounted and distributed over a project’s lifespan.
<u>Interpretation:</u> the cost benefit analysis has two results. The efficiency criterion seems to be a fair parameter for comparing alternatives. The benefit-cost difference obviously tends to prefer big infrastructure projects over smaller ones. Besides, all external effects have to be monetarized before being taken into account.
The unique feature of the **lifecycle cost analysis** is its ability to ultimately display a project’s annuity as parameter for comparison. Since the indicator values of all selected decision criteria are discounted over a project’s expected lifespan, even projects with different lifespans can be compared to one another. Additionally, it is possible to publish intermediate accounts for investors, ridership or third parties. For example the amortization time can easily be assessed.
<u>Interpretation:</u> The lifecycle cost analysis results in an explicit recommendation for one alternative, independent from different alternatives‘ lifespans. It seems to provide the most holistic picture. In order to give a reliable forecast over an entire lifecycle, arising expenses have to be estimated well - regarding both time and volume. Additionally, external effects have to be monetarized over the whole lifecycle – not taking into account future social and environmental developments.

According to (Tudela, Akiki, & Cisternas, 2005), the **multi criteria analysis** is the most appropriate evaluation method in the field of decision making for infrastructure projects of any kind since they usually have multiple interdependent targets. In contrast to the methods mentioned above, the analytical hierarchy process (AHP) as a prime example for a multi criteria analysis converts a complex decision making process into a hierarchical structure. First targets are ranked (main target and subordinates). In the next step, decision criteria are rated in pairs, which ultimately leads to a consistent ranking of criteria (based on points given). Similarly, the alternatives are compared in pairs regarding the predefined and ranked decision criteria. They are also awarded with points according to their performance in each field. By using a mathematical model (not further elaborated in this paper), all criteria are carefully weighed. Finally, the different alternatives are ranked according to their performance and the criteria's hierarchy.
Interpretation: A multi criteria analysis like the AHP is a complex computerized mathematical model. Nevertheless, in this analysis, all decision criteria can be adequately taken into account without the need of monetarizing them before. Albeit complex, the AHP best takes into account external effects and other soft factors.
Based on the interpretations, Table 3 gives an overview over the strengths and weaknesses of the different analysis methods. Therefore, all methods have been rated concerning three criteria. Calculation effort characterizes the complexity of the underlying mathematical algorithm while required data accuracy states how precise input data has to be. For example, lifecycle cost analysis results in a precise and long term forecast. That is why its input data accuracy has to be extremely high. The last criterion is a method's ability to take non-monetary criteria into account. Whenever non-monetary criteria have to be translated into a monetary value to be taken into account, which leaves lots of room for inaccuracy. Multi criteria analysis, although it leads to high calculation efforts, is therefore found to be most suitable for decision-making processes in the field of modal choice for public transport systems. It does not require full data accuracy and can very well take decision criteria of any kind into account.

Table 3
Comparison of evaluation methods

evaluation method	calculation effort	required data accuracy	consideration of non-monetary criteria
Impact analysis	**very low**	**low**	**good**
Benefit analysis	**low**	**average**	**good**
Cost-impact analysis	**low**	**average**	**good**
Cost-benefit analysis	**average**	**high**	**average**
Lifecycle cost analysis	**high**	**high**	**average**
Multi criteria analysis	**high**	**low**	**very good**

Source: (Kehrer, 2013)

4. Case studies: actual decision making

In this part, actual ongoing decision making processes are investigated with a focus on potential differences between the actual and the ideal process. Therefore, two such processes have been selected in the Austrian cities of Linz and Graz.

4.1. Second tram axis, Linz

In Linz, a city of nearly 200.000 inhabitants, two projects are currently under consideration: On the one hand, the "Mühlkreisbahn", a heavy rail line starting in the North of Linz, linking the north western hinterland to the city center, which is entirely isolated from the Austrian federal railway network and should somehow be integrated in an existing network. Political players favour a so called "tramtrain" which means a convertion of the heavy rail tracks to the narrow gauge tram tracks and an integration into the existing tram network of Linz.
The second project is an additional, 4,7 km long tram axis crossing the city center of Linz, linking the Northern branches of the network with the Southern ones. So far, only one overloaded axis connects the two parts of the network. The route of the second link has already been chosen. However, two options of alignment were considered: either leading the tracks on the surface in mixed traffic or accelerated mixed traffic, or building a tunnel structure.
Two areas of decision making could be identified:

- Modal choice for future operations on the existing "Mühlkreisbahn",
- Alignment of the second tram axis either on the surface or in a tunnel.

Due to operational reasons, a modal choice for the second public transport axis had not been taken into consideration.
As a hindrance for target seeking decision making as shown in the ideal decision making process, both areas of decision making have been politically debated in public. That is why political decision makers have declared their preferences early in the process. The only evaluation method for the modal choice of the "Mühlkreisbahn" so far is a feasibility study, a comparison of different alternatives was not done. The feasibility study is not available to the public.
The second tram axis through the city center had unanimously been decided in the city council of Linz without taking different transport systems into account. However, that decision appears plausible since the bottleneck of the tram network leads to unreliable operations.

In order to determine whether this axis should run on the surface or underground, a cost-benefit analysis has been carried out. The results were never made available to the public. Different sources claim that the costs for the underground alternative would be ten times the costs for the surface alternative. There has not been a comparison between the cost-benefit analyses of the two alternatives. However, transport authorities in Linz claim, the surface alternative would not be feasible due to "insuperable conflicts with car traffic."
The interests of tradespeople along the new tram axis are a special decision criterion taken into account in this process. In the beginning, they were in favour of the surface alternative. After an "information event" by the transport authorities of Linz, they changed their mind and now prefer the underground alternative.

4.2. Additional city crossing, Graz

In Graz (265.000 inhabitants) all 6 tram lines currently use the one city crossing through the "Herrengasse", a pedestrian area with lots of shops and restaurants. Similarly to Linz, the northern and southern branches of the network are only connected by this bottleneck. Brought up by political decision makers, a urban cable car along the river "Mur" has also been brought up to relieve the overcrowded tram lines through the "Herrengasse". Another goal is to increase the tram network's capacity due to an annual increase in ridership of about 2 to 3 %.
The following two areas of decision making have been identified:

- Modal choice for another city crossing,
- Increasing capacity of the existing tram network.

The urban cable car and a potential second tram axis connecting the northern and southern branches of the network, both alternatives have been regarded separately, the cable car has never been seen as an alternative to the tram link but as a separate project.
A feasibility study for the urban cable car was carried out and a cost estimation was published, estimating costs at 92 million Euros. Although this price had been published, the study never was. The feasibility study is only now being used for political lobbying.
Experts have compared different alternatives for the second tram link based on their feasibility. Since technical constraints such as curve radiuses and soft factors like expected vibration emissions in narrow roads already eliminated multiple alternatives, the route through "Elisabethstraße" emerged as the only one feasible and reasonable. This analysis – albeit not published – can be seen as an impact analysis as a basis for decision making.
In the second area of decision making, the acquisition of longer trams on the one hand and denser intervals on the other hand have been named as alternative approaches. Costs have been assessed for both alternatives and have been directly compared – favouring the acquisition of longer trams because of their lower costs. However, the use for ridership was not taken into account although denser intervals increase the comfort for ridership while longer trains only increase capacity. In town council in Graz, the decision for purchasing long trains was made.

5. Conclusion: Actual vs. target decision making

A comparison between the ideal decision making process in chapter 4, using a proper evaluation method to take into account multiple decision criteria as identified in chapter 3 and the actual decision making processes from the case studies in Linz and Graz, shows the following differences:

- Instead of a target-seeking approach driven by existing problems as being the very first step in the ideal decision making process both cities' areas of decision concerning modal choice are clearly target-oriented. Political decision-makers have favoured a certain solution from the very beginning. In Linz, the decision for a "tramtrain" has widely been promoted, while in Graz the tram link appears to be simply necessary while the urban cable car is politically driven – without taking other options under consideration,
- The second step of the process, finding alternatives, has been carried out for only two of the four areas of decision making – the alignment of the second tram axis in Linz as well as the increase in capacity in Graz,
- An impact analysis was only made in the case of raising the capacity of the tram network in Graz. Feasibility was checked for all areas of decision making,
- The following steps, where advantages, disadvantages and efficiency are tested, all alternatives are compared and finally the best option is named, in the ideal process has hardly been done in any of the defined areas of decision making in Graz and Linz. Although in Linz a cost-benefit analysis was carried out, it was only done for one option, leaving no room for comparison. In Graz, concerning the increase in capacity, costs were compared without displaying benefits of the alternatives,
- Decision criteria as outlined in chapter 3 have hardly been taken into account in the present actual decision making processes.

This comparison shows, that there is a huge gap between actual and target decision making in the field of public transportation. Although investments are large and usually funded by public authorities, the present decision making processes in Graz and Linz are not transparent processes.

Decision criteria that should be taken into account when comparing alternatives are hardly taken into account at all while methods for evaluation are sparsely used. Only fragments of the ideal decision making process can be identified in the actual processes.

This paper gives a recommendation for an ideal decision making process for the field of public transportation, i.e. modal choice. Apart from transport systems that should be taken into account, decision criteria that pose a significant impact on the environment were identified and were correlated with the named transport systems. However, the comparison with actual decision making processes show that political will and a target-oriented approach hinder an efficient, fair decision making process. Extending and evaluating the list of decision criteria that should be taken into account, as well as transport systems regarded, could be subjects for further research. Besides, more actual case studies could be compared to an ideal decision making process.

The findings of this paper draw a disillusioning picture and shows that arbitrary decisions seem to be the general rule.

References

Alshalalfah, B.; Shalaby, A. 2010. *Aerial Ropeway Transit: State of the ART*, University of Toronto, Toronto, Canada.

Anderhub, G.; Dorbritz, R.; Weidmann, U. 2008. *Leistungsfähigkeitsbestimmung öffentlicher Verkehrssysteme*, ETH Zürich, Zürich, Switzerland.

Brezina, T. 2004. *An Integration of human transport planning criteria in the design of a light rail system with an application to Ljubljana*, TU Wien, Wien, Austria.

Brezina, T.; Hader, T.; Eder, E. 2015. *Pendeln in der Ostregion - Potenziale für die Bahn*, Kammer für Arbeiter und Angestellte für Wien, Wien, Austria.

De Bruijn, H.; Veeneman, W. 2009. Decision-making for light rail, *Transportation Research Part A*, 43: 349-359.

Deutsch, V. 2003. *Einsatzbereiche neuartiger Transportsysteme zwischen Bus und Bahn*, Bergische Universität Wuppertal, Wuppertal, Germany.

Hoffmann, M. 2013. *Lebenszykluskosten der Straßeninfrastruktur - Ansätze zur Optimierung von Investitionsstrategien und technischen Maßnahmen, Bau- und Betriebsweisen für Straßenanlagen in ihrem Lebenszyklus*, TU Wien, Wien, Austria.

Huang, C.F.; Xia, Y. 2011. Research on the role of urban rail transit in promoting economic development, *Procedia Engineering*, 21: 520-525.

Ibeas, A.; Cordera, R.; Dell'Olio, L.; Coppola, P.; Dominguez, A. 2012. Modelling transport and real-estate values interactions in urban systems, *Transport Geography*, 24: 370-382.

Kehrer, J. 2013. *Entscheidungskriterien für die Systemwahl im öffentlichen Personennahverkehr*, TU Wien - Institut für Verkehrswissenschaften, Wien, Austria.

Pagliara, F.; Papa, E. 2011. Urban rail systems investments: an analysis of the impacts on property values and residents' location, *Journal of Transport Geography*, 19(2): 200-211.

Rollinger, W.; Emberger, G.; Brezina, T. 2009. *Handbuch Öffentlicher Verkehr, Schwerpunkt Österreich*, ÖVG, Wien, Austria.

Steierwald, G.; Kühne, H.D.; Vogt, W. 2005. *Stadtverkehrsplanung*, Springer-Verlag Berlin Heidelberg, Stuttgart, Germany.

Stoop, J.; Thissen, W. 1997. Transport Safety: Trends and Challenges from a Systems Perspective, *Safety Sciences*, 26(1-2): 107-120.

Tudela, A.; Akiki, N.; Cisternas, R. 2005. Comparing the output of cost benefit and multi-criteria analysis An application to urban transport investments, *Transportation Research Part A*, 40(5): 414-423.

Vuchic, V. 2007. *Urban Transport, Systems and Technology*, John Wiley & Sons Inc, New Jersey, U.S.A.

Zhibin, L.; Wei, W.; Xuedong, H.; Chen, Y.; Yaotian, Z. 2010. *Quantitative Analysis of Impact of External Cost on Urban Passenger Transport Structure*, Transportation School Southeast University, Nanjing, China.

THE SELECTION OF AN APPROPRIATE DISTRUBUTION CHANNEL

David Hrdý[1], Petr Průša[2]

[1,2] University of Pardubice, Jan Perner Transport Faculty, Department of Transport management, marketing and logistics, Pardubice, Czech Republic

Abstract: Selection of distribution channel type is an important decision of every manufacturing company. Appropriate choice of distribution channel can save a considerable cost while maintaining a high level of customer service. Determination of an appropriate strategy for the management of enterprise distribution channel.

Keywords: distribution logistics, distribution channel, ANP.

1. Introduction

In this article, the selection of the type of distribution channel is proposed using ANP method to determine the strength of influence of input factors on the target set of potential options.
Submitted model is very clear, understandable and according to the proposed methodology easy to implement, while also providing clear and understandable results during selection of the type of distribution channel.
The proposed model is primarily targeting for distribution of high value stone which need to decide which distribution strategy should be chosen or if to switch to another distribution strategy more suitable for the company needs. From the perspective of Multiple Criteria Decision-Analysis (MCDM) there is a wide range of methods used for dealing with choice of not only the type of distribution channel. MCDM history goes back about 40 years ago, with Alias, et al. (2008) reviewed over 70 of these techniques. Aruldoss et al. (2013), for example, compiled the inventory of multi-criterial methods with examples of their application. A plenty of studies uses MDCM to select and evaluate a supplier. Ho, et. al. (2010) and Agarwal, et. al. (2011) prepared a summary of MCDM techniques and their use in choosing a supplier evaluation (Table 1).

Table 1
Review of MCDM techniques in the scientific literature

	Technique	Authors
Individual Approach	Data Envelopment Analysis (DEA)	Liu et al. (2000); Narasimhan et al. (2001); Talluri and Sarkis (2002); Sedel (2006); Saen (2007)
	Mathematical Programming	Wadhwan and Ravindran (2007); Narasimhan et al. (2006); Hong et al. (2005)
	Analytic Hierarchy Process (AHP)	Chan (2003); Liu and Hai (2005); Hou and Su (2007)
	Analytic Network Process (ANP)	Sarkis and Talluri (2002); Bayzit (2006); Gencer and Mohapatra (2006)
	Case-based reasoning (CBR)	Choy and Lee (2002); Choy et al. (2005)
	Fuzzy Methods (FST)	Sarkis and Mohapatra (2006); Florez Lopez (2007)
Combined Approach	AHP - DEA	Ramanathan (2007); Saen (2007); Sevkil et al. (2007)
	AHP - DEA - ANN	Ha and Krishman (2008)
	AHP - MODM	Xia and Wu (2007)
	ANN - CBR	Choy et al. (2003; 2004)
	ANN - MODM	Demirtas and USTUn (2008)
	DEA - MODM	Weber et al. (2000); Talluri et al. (2008)

Source: (Authors)

Singh & Malik, (2014) divided MCDM in their work into two categories: Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM). MADM focuses on the selection of the best alternative from the set of pre-defined alternatives where the set is limited by a number of input factors (Rao, 2007). One of the recent studies (Bernroider and Mitlöhner, 2015) seeks to raise awareness about the methodology of Multiple-attribute of Decision Making (MADM) in connection with Enterprise Resource plannig (ERP) projects. MODM on the other hand focuses on the design alternatives on the basis of the input factors (Zhang and Ruan, 2007). The possibilities are usually endless and aim is to choose the possibility that best fits the constraints and priorities set by the decision maker.

[1] Corresponding author: hrdy.david@gmail.com

The basis for the decision making in MCDM is Saaty‘s approach, which builds on a large number of studies. Sha and Che, (2006) used the AHP method to design a distribution chain network, where the focus was on the selection of a suitable partner, planning, distribution and manufacturing. Kahraman et al. (2003) dealt with a supplier selection using MCDM approach with help of the so-called Fuzzy AHP method.
The MCDM approach has appeared in a number of studies focused on distribution logistics. Mallen (1996) used this approach to select the distribution channel, where was this selection subdivided into several stages. Ho and Emrouznejad (2009) used a combination of AHP methods and logical operators for structural design of a distribution grid. Nilay Serbest and Vayvay (2008) proposed a model for selecting the most appropriate distribution channel using fuzzy AHP method.

2. Problem definition

Only very few manufacturers sell their goods directly to the final consumer. Between the producer and the final consumer there is a number of intermediaries, which make up the distribution chain. Distribution chain then can be understood as "part of the logistics chain that begins when the product leaves the company and ends at the final customer". Zylstra (2012) defined the objective of distribution chain as an overcoming of the time, space and property inconsistencies in the course of the movement of goods and services to customers. The structure of the distribution chain is determined by functions / activities that each organization in the chain carries out. From the discussed company’s perspective, which is the position of the manufacturer, its aim is to optimize distribution logistics for the customer. The aim is to design and build a suitable model for selecting the distribution chain, which will help the company reduce losses in the distribution part of the logistics chain. Discussed company currently uses the local branches in the Czech and Slovak Republic. The given model should provide an answer as to whether this is desirable or recommend switching to another type of distribution channel.
Lambert (2000) stated that most of the distribution chains is formed as a network of vertically aligned companies, without any fixed structure. The specific structure largely depends on the nature of the distributed product and nature of the target market of the company. Even for companies producing similar products the "best" structure of the distribution chain cannot be unambiguously determined (Gašparík, 2006). This should be created in relation to the overall business and marketing objectives of the company. The distribution chains thus differ in their length and width. Length is the number of distribution levels between the manufacturer and the customer. The width is given by the number of participants involved in the distribution at given level.
The distribution system must be therefore regularly inspected and modified by the manufacturer. Modification of distribution channels is essential if they are not functioning as planned, or if the shopping behaviour of customers changed, the market expanded, new competition appeared, new ways of distribution are created or product moves to the next stage of its life cycle. No distribution channel remains competitive throughout the product’s whole life cycle (Rosová, 2007). The first potential customers may be willing to pay the price for a big customer added-value, but other potential customers will move to a cheaper distribution routes.

3. Logical framework of the proposed model

The proposed model is based on the goal definition of the proposed study because of both maximization and minimization factors, and also include the dependencies between these factors (Kunz, 2010). To create the model all alternatives must be related to all limiting factors. As already mentioned, the creation of a model for the choice of distribution channel must take into account both the company’s perspective (minimization of cost factors) and the customer ‘s perspective (maximization of customer service factors).

3.1. Alternatives

A high importance is apparent when selecting a suitable distribution model for the given company. Distribution costs vary with the use of different types of distribution channels and it is at the discretion of company management to state its goal. For the proposed model four basic types of distribution channels were identified:

- ***Direct distribution*** - Products are stored in a central warehouse, or directly at the manufacturer, without the use of distribution centres in the distribution chain. Orders are processed directly and manufacturer delivers the order directly to the customer,
- ***Cross-dock centre*** - goods are assembled, merged, or tailored to customer requirements only after the production in cross-dock centre with added value. The customer receives the all his orders in one package.
- ***Local branches or warehouses / distribution centres*** - local branches cover the market in order to achieve a strategic position for the customer.
- ***Offtake by the customer*** - storage is provided in warehouses, or directly at the manufacturer (also in local offices), with the difference that the picking up of the goods is directed by the customer.

3.2. Selected factors of customer service

From the customer's perspective it is important to maximize customer service. Costantino and Di Graviá (2014) determined the factors of customer service, affecting the production rate of individual types of distribution channels. Adjusted factors useful for the proposed model are:

- ***Product Availability*** **-** period determining how available the demanded product is in distribution chain, it is a unit of time, it is goal is to maximize system availability,
- ***Customer satisfaction*** **-** a factor tracking customer‘s satisfaction with a type of the distribution chain. It is obtained by querying about customer's experience, it is goal is to achieve maximum customer satisfaction.
- ***Consolidation of orders*** **-** not all types of distribution chains are suitable for merging orders, the goal is to merge multiple potential orders so that the customer receives only one complete order,
- ***Order tracking*** **-** an important factor guaranteeing the possibility of accurate tracking of orders throughout the whole order process,
- ***Reliability of supply*** **-** the percent accuracy of ordered goods delivery,
- ***Speed of delivery*** **-** or also the distribution chain performance, measuring the speed of delivery of orders,
- ***Reverse logistics*** – the difficulty of reverse logistics for different types of distribution channels.

3.3. Selected cost criteria

Perspective of the company is limited by cost factors (Costantino and Di Graviá, 2014). Revised factors are:

- Information **-** in the distribution chain everything has to be properly monitored, planned and kept in records, This obviously results in rising of costs for each different distribution channels,
- Storage **-** every distribution channel retains a certain quantity of goods, which raises the cost of storage, handling, transportation within the warehouse etc. Expenses again depend on a type of distribution channel,
- Operational – covers all expenses related to the management and administration of the given type of distribution channel. More complex distribution channel arrangement results in higher operating costs,
- Boot **-** the initial costs of implementing new type of distribution channel, or the cost of switching to this channel from another type of distribution channel,
- Transport **-** traffic volume in the transport chain. Cost factor with big influences on the final results of cost criteria.

4. Proposed model

To achieve the best possible results in the choice of the type of grid a two-phase model was designed. The model uses a modified version of Delphi method and a method of ANP, which provides partial results subsequently used in the TOPSIS method. The process of the proposed model is shown in Figure 1:

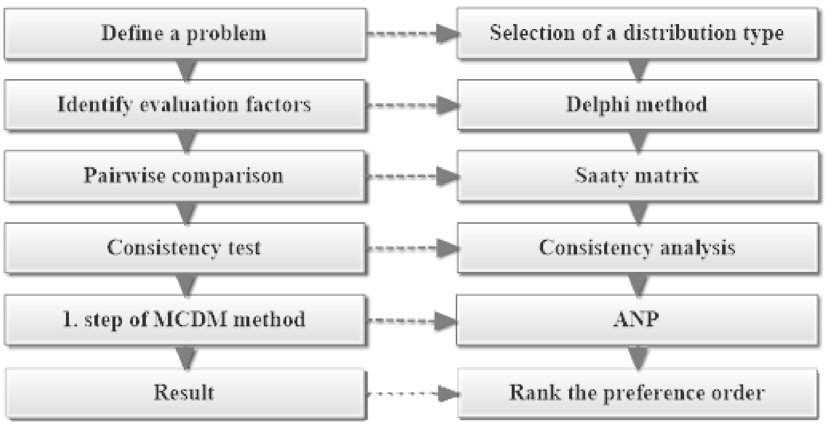


Fig. 1.
Proposed model

I. Delphi method

The first and most important step of the proposed model is a pairwise comparison of input factors and their influence on the resulting type of distribution routes. For this purpose, there is an assembled group of evaluators, consisting of logistics managers, researchers, but also professionals, in order to achieve the most correct evaluation of these factors possible.

For this purpose, the proposed method is Delphi (Linstone and Turoff, 1975) which is suitable for the determination of a professional estimate by a selected group of people. It's a technique that uses subjective opinions of members of the expert group in order to obtain an overall consensus views. Delphi method can be simply seen as a kind of brainstorming session with clear rules.

II. Saaty method

To obtain the weighting of individual factors a use of Saaty method is recommended (1980). The input to this method is the pairwise comparison of individual factors obtained in Step I. Each expert group is also assigned a weight, which represents the degree of influence on the resulting model.

This method takes into account different preferences between criteria and a wide range scoring scale, which is intended for evaluation (Formula 1). Therefore, it is possible to detect even slight differences in preferences between the selected criteria, using the process of determining weight:

$$(s_{ij}) = \begin{cases} 1 - i \text{ and } j \text{ are equals;} \\ 3 - i \text{ is slightly favour over } j; \\ 5 - i \text{ is strongly favour over } j; \\ 7 - i \text{ is very strongly favour over } j; \\ 9 - i \text{ is absolutely favour over } j; \end{cases} \tag{1}$$

Values of 2, 4, 6, 8 are designed for evaluation of so-called interphase. This method compares each pair of criteria i and j. Their evaluations is entered in the Saaty matrix (Formula 2), according to the following rules:

$$S = \begin{pmatrix} 1 & s_{12} & \cdots & s_{1k} \\ {}^{1}/_{s_{12}} & 1 & \cdots & s_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ {}^{1}/_{s_{1k}} & {}^{1}/_{s_{2k}} & \cdots & 1 \end{pmatrix} \tag{2}$$

This methods is comprised of five steps (Saaty, 1980), which include weight calculation ν_i by using standardized geometric mean of Saaty matrix's rows.

III. Consistency analysis

An important factor to whom it is necessary to pay attention during pairwise comparison is consistency (Saaty, 1980). In case that we do not only transfer the exact measurements to elemental scale but use judgment, there is almost always inconsistency. (If we say that a is 3 times greater than b, but only 1/5 times as good as c, c would have to be 15-times better than b to avoid inconsistency.) Given the characteristics of reciprocal matrices and eigenvalues the minor inconsistency does not have any effect during determining the vector priorities.

The degree of consistency below the 0.10 (10%) value is considered acceptable (Chan et al., 2006). For higher values the pairwise comparison matrix should be adjusted, otherwise the results of the entire model quickly lose their predictive value. Experimentally derived RI values reported by Saaty (1980) for a matrix of order 1-15 are shown in Table 2:

Table 2

Experimentally derived RI values

Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Source: Saaty (1980)

IV. AHP / ANP method (Analytic Hierarchy Proces / Analytic Network Process)

Method of AHP (Saat, 1980, 1994), which is widely discussed in literature (Isiklar and Buyukozkan, 2007; Onut and Soner, 2007; Wu et al., 2009) is a method for priority setting which derives the relative priority based on pairwise comparisons of elements at the same hierarchical level using the absolute numbers at range from 1 to 9. Analytic Hierarchy Process (AHP) is a method that is appropriate for the hierarchical structure of the systems.

Absolute numbers of the scale are approximations of weights ratio w_j/w_k which make it possible to deduce the weights of w_j and w_k. AHP method uses a general model for the weight synthesis in a hierarchical structure where w_{ij} are local weights of $_i$ element on a given level with relation to the j element from previous level of hierarchical structure, w_j are weights of elements of previous levels of hierarchical structure and ui is a global element weight in terms of all elements of the previous hierarchical structure levels. Mathematically AHP method simply enrols via 3 steps, where we proceed from pairwise comparison matrix (Formula 2):

Method of ANP (Analytic Network Process) is a network generalization of AHP method (Analytic Hierarchy Process). Analytic network process (ANP) is a method that allows the system to include all possible interdependencies and feedbacks (Saaty, 2001). Strategic partnership of the chain units can be modelled using network structures. The structure of the ANP model is suitable for expressing dependencies within the network of supply / distribution relationships, where units of supply / distribution chains can be grouped into so-called clusters and linked by streams affecting their dependency. These model clusters can represent suppliers, manufacturers, distributors, customers and

these links between clusters represent possible influences between elements of different clusters and loops at individual clusters represent possible links between elements of the cluster.
For dealing with the network structures using ANP. There is a program available named Super Decisions by CDF company (Creative Decisions Foundation), which will be used in the proposed model.

5. The application of the proposed model

To determine the most accurate values of pairwise comparison there were three groups of evaluators created. The first group was composed practitioners in the form of logistics manager, purchasing manager and sales director. The second group consisted of a group of scientists, dealing with logistics, which drew on currently available studies and their own experience. The third group was the professional community, using different types of distribution channels in the form of transporters, customers and end customers.

I. Determination of input factors and suitable alternatives using a modified Delphi method

A model was designed based on the Delphi method, consisting of input conditions containing costs relevant to the choice of type of the distribution chain and the level of individual services, occurring in the distribution chain. From the perspective of each alternative of distribution channels four suggested types from Chapter II were assessed (Table 3):

Table 3
Input factors and a set of options for the proposed model

Selection of a distribution channel type	**FC - Costs**	FC1 - Information	**A - Alternatives**	A1 - Offtake by the customer
		FC2 - Storage		
		FC3 - Operational		A2 - Direct distribution
		FC4 - Boot		
		FC5 - Transport		
	FSL – Customer service	FSL1 - Product Availability		
		FSL2 - Customer satisfaction		A3 - Local branches or warehouses / distribution centers
		FSL3 - Consolidation of orders		
		FSL4 - Order tracking		
		FSL5 - Reliability of supply		A4 - Cross-dock center
		FSL6 - Speed of delivery		
		FSL7 - Reverse logistics		

Source: (Authors)

II. Assembling the resulting pairwise comparison matrix by using Saaty method

From the three resulting matrices obtained from each groups of evaluators, the resulting matrix was calculated using the Saaty method. Individual groups were assigned a weight according to the degree of their influence on the final model (Table 5). The resulting matrix is displayed is shown in the Table 6 and 7.

III. Determination of the linkages and the resulting weights by ANP

To determine the mutual linkages and calculate the resulting weights a Super Decisions program by CDF was used, which is useful in solving problems with multiple interrelated input factors. Solution by using AHP method would be slow and inefficient. The assembled model in the program is shown in Figure 2.

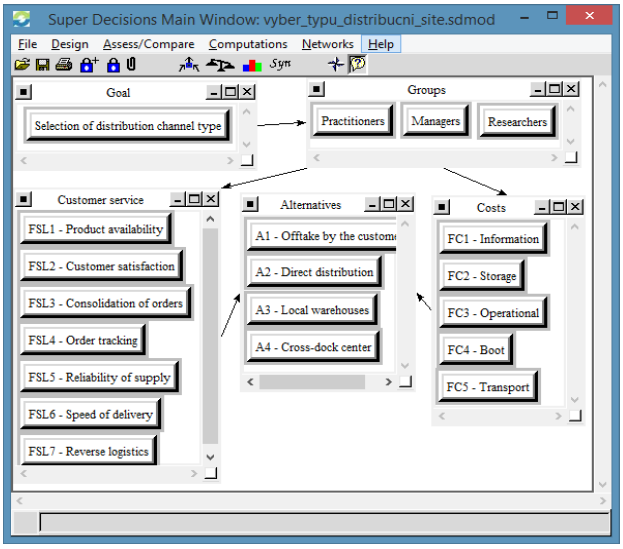


Fig. 2.
Proposed ANP model
Source :(Authors)

Paired comparisons obtained by using method of Delphi in step II. was entered into the program to individual evaluation groups and by exporting a unweighted matrix was obtained for each factor. This matrix is shown in Table 4 and 5.

Table 4
Unweighted ANP matrix of cost criteria

ANP matrix pro FC	*FC1*	*FC2*	*FC3*	*FC4*	*FC5*
A1	0.4587	0.0346	0.3225	0.0473	0.4364
A2	0.1508	0.5475	0.4860	0.6210	0.0857
A3	0.3558	0.1078	0.1094	0.0622	0.2601
A4	0.0348	0.3101	0.0821	0.2694	0.2178

Source :(Authors)

Table 5
Unweighted ANP matrix of customer service

ANP matrix pro FCL	*FSL1*	*FSL2*	*FSL3*	*FSL4*	*FSL5*	*FSL6*	*FSL7*
A1	0.0419	0.4177	0.2654	0.0500	0.1768	0.5426	0.6629
A2	0.5329	0.0776	0.0344	0.1800	0.0845	0.0401	0.0449
A3	0.0608	0.1746	0.1821	0.0858	0.2754	0.3352	0.2270
A4	0.3643	0.3301	0.5180	0.6842	0.4634	0.0821	0.0652

Source :(Authors)

In conclusion, we calculate the proposed model using an ANP method. The results are shown in Table 6.

Table 6
Result of the ANP method

Name	*Ideal*	*Normal*	*Raw*
A1 - Offtake by the customer	0.864610	0.277077	0.092359
A2 - Direct distribution	0.689286	0.220892	0.073631
A3 - Local warehouses	0.566574	0.181567	0.060522
A4 - Cross-dock center	1.000000	0.320465	0.106822

Source :(Authors)

The results are clear. The best option for the proposed issue is set up a distribution channel with one cross-dock centre or warehouse placed on the targeting market. The results have been counted with an APN method and 3 different values has been shown. Column Ideals (ideal variants) shows a variant with the higher weight as an ideal variant and the others are its shares. These results are used for comparing values between each other. Normal (normalized variants) shows weights normalized in the exact way then their sum is equal 1. These values we can see in the AHP method. Raw (gross variants) is a vector acquired directly from limited super matrix. These values are useful for future counting. The table 6 is graphically illustrated in Figure 3.

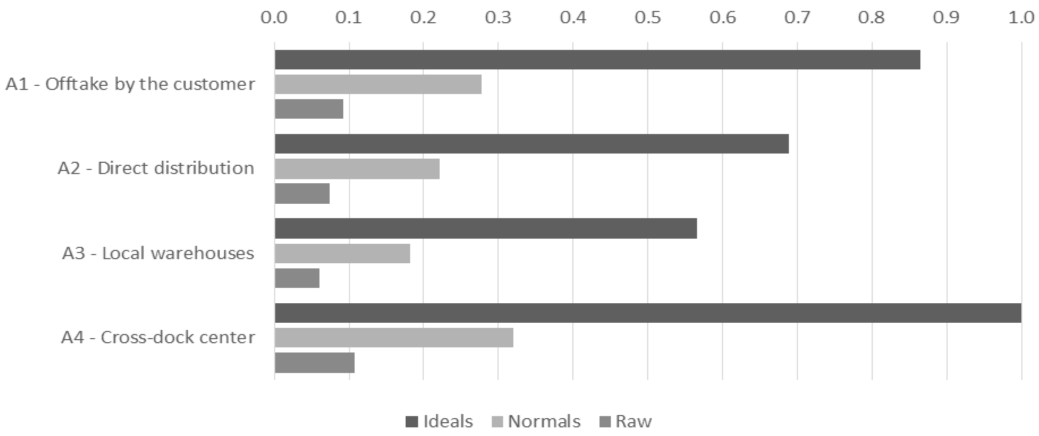


Fig. 3.
Graph of the results of the ANP method

Source :(Authors)

The model results clearly show that the current model in the form of local branches is the least appropriate one. Introducing distribution channel in the form of cross-dock centre for the company is preferable from the viewpoint of the level of customer service and of the significant reduction of costs, which is shown primarily by eliminating losses in the distribution channel. The company cannot afford the complete abolition of local branches due to a local dealership, so the reduction will be implemented in local warehouses, which will result in sufficient cost reductions.

6. Conclusions and final discussion

Appropriate choice of the type of distribution channel can save the enterprise considerable amount of financial resources. This article focused on designing and building a model for selection of a suitable type of distribution channel, mainly for to the expenses reduction of existing distribution channel and simultaneously for assessment of its suitability for the company.

The proposed model provides a clear insight on the discussed issues of selecting the type of distribution channel for the company's management while considering various input factors, with the possibility to modify these factors within the proposed model. The presented model is able to work with both qualitative and quantitative criteria.

Despite the quality and clarity of the proposed model, the greatest threat to the accuracy and relevance of the model is the input formation of pair evaluation. This evaluation may have a profound impact on the outcome of the model and even at small inconsistency level of input evaluation the outcome may be affected. In the presented model, this is prevented by setting up three major evaluation teams of more members which ensures removal of fluctuations or inconsistency of evaluation. For each pair evaluation there is also a consistency analysis which immediately warns you. about any evaluation discrepancy.

Acknowledgements

The authors would like to thank everyone who participated in this research for their valuable suggestions, comments and ratings. Big thanks also goes to all employees of the discussed company for their patience and willingness during the input evaluation processing for the model creation. The work was created in connection with the scientific research project of the University of Pardubice no. 51030/20/SG550001.

References

Agarwal, P.; Sahai, M.; Mishra, V.; Bag, M.; Singh, V. 2011. A review of multi-criteria decision making techniques for supplier evaluation and selection, *International journal of industrial engineering computations*, 2(4): 801-810.

Alias, M.A.; Hashim, M.; Zaiton, S.; Samsudin, S. 2008. Multi criteria decision making and its applications: a literature review, *Jurnal Teknologi Maklumat*, 20(2): 129-152.

Aruldoss, M.; Lakshmi, T.M.; Venkatesan, V.P. 2013. A survey on multi criteria decision making methods and its applications, *American Journal of Information Systems*, 1(1): 31-43.

Bernroider, E.W.; Mitlohner, J. 2015. Characteristics of the multiple attribute decision making methodology in enterprise resource planning software decisions, *Communications of the IIMA*, 5(1): 48-58.

Costantino, F.; Di Gravio, G.; Shaban, A. 2014. Multi-criteria logistics distribution network design for mass customization, *International Journal of Applied Decision Sciences*, 7(2): 151-167.

Gašparík, J. 2006. Definovanie predajných kanálov železničného podniku, *Perner´s Contacts*, 1(2): 3-9.

Ho, W.; Emrouznejad, A. 2009. Multi-criteria logistics distribution network design using SAS/OR, *Expert Systems with Applications*, 36(3): 7288-7298.

Ho, W.; Xu, X.; Dey, P. K. 2010. Multi-criteria decision making approaches for supplier evaluation and selection: A literature review, *European Journal of Operational Research*, 202(1): 16-24.

Chan, F.T.S.; Chan, H.K.; Lau, H.C.W.; Ip, R.W.L. 2006. An AHP approach in benchmarking logistics performance of the postal industry, *Benchmarking: An International Journal*, 13(6): 636-61.

Isıklar, G.; Buyukozkan, G. 2007. Using a multi-criteria decision making approach to evaluate mobile phone alternatives, *Computer Standards & Interfaces*, 29(4): 265-74.

Isıklar, G.; Alptekin, E.; Buyukozkan, G. 2007. Application of a hybrid intelligent decision support model in logistics outsourcing, *Computers & Operation Research*, 34(3): 3701-14.

Kahraman, C.; Cebeci, U.; Ulukan, Z. 2003. Multi-criteria supplier selection using fuzzy AHP, *Logistics Information Management*, 16(6): 382-394.

Kunz, J. 2010. Complexity of performance measures and decision quality, *International Journal of Applied Decision Sciences*, 3(4): 331-337.

Linstone, H.A.; Turoff, M. 1975. *The Delphi method: Techniques and applications*, Addison-Wesley Pub. Co, Boston, U.S.A.

Lu, J.; Zhang, G.; Ruan, D. 2007. *Multi-objective group decision making: methods, software and applications with fuzzy set techniques*, Imperial College Press, London, UK.

Mallen, B. 1996. Selecting channels of distribution: a multi-stage process, *International Journal of Physical Distribution & Logistics Management*, 26(5): 5-21.

Nilay Serbest, G.; Vayvay, O. 2008. Selection of the most suitable distribution channel using fuzzy analytic hierarchy process in Turkey, *International Journal of Logistics Systems and Management,* 4(5): 487-505.

Onut, S.; Soner, S. 2007. Transshipment site selection using the AHP and TOPSIS approaches under fuzzy environment, *Waste Management*, 28(2): 1552-9.

Qureshi, M.N.; Kumar, P.; Kumar, D. 2013. Selection of Transportation Company: An analytic network process (ANP) approach, *ICFAI Journal of Supply Chain Management*, 6(2): 274-289.

Rao, R.V. 2007. *Decision Making in the Manufacturing Environment: Using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods*, Sprigner Series in Advanced Manufacturing, UK.

Rosová, A. 2007. Logistické náklady podniku, *Acta Montanistica Slovaca*, 2(12): 121-127.

Saaty, T.L. 1980. *The Analytic Hierarchy Process*, McGraw-Hill, New York, U.S.A.

Saaty, T.L. 1994. How to make a decision: the analytic hierarchy process, *Interfaces*, 24(6): 19-43.

Selçuk P. 2009. Evaluation of third-party logistics (3PL) providers by using a two phase AHP and TOPSIS methodology, *Benchmarking: An International Journal*, 16(5): 588 – 604.

Sha, D.Y.; Che, Z.H. 2006. Supply chain network design: partner selection and production/distribution planning using a systematic model, *Journal of the Operational Research Society* 57(1): 52-62.

Singh, A.; Malik, S. K. 2014. Major MCDM Techniques and their application-A Review, *IOSR Journal of Engineering*, 4(5): 15-25.

Wu, C.R.; Lin, C.T.; Lin, Y.F. 2009. Selecting the preferable bancassurance alliance strategic by using expert group decision technique, *Expert Systems with Applications* 36(2): 189-197.

Zylstra, K.D. 2012. *Lean distribution: Applying lean manufacturing to distribution, logistics, and supply chain*. John Wiley & Sons, Hoboken, U.S.A.

RISK ANALYSIS OF INVESTMENT IN WATERWAY INFRASTRUCTURE

Miroslav Bartoš[1], Hana Záhorská[2], Vít Hromádka[3], Eva Vítková[4], Miloš Waldhans[5]
[1,2,3,4,5] *Brno University of Technology, Faculty of Civil Engineering, Czech Republic*

Abstract: The project represents a unique process consisting of a number of dependent activities that bear great amount of risk. To ensure the success rate of the project, it is necessary to deal with risks already in the pre-investment phase, which can be done using the risk analysis, i.e. an inseparable part of the decision-making process regarding the feasibility of an investment. This article deals with investment in waterway infrastructure, namely in the Elbe waterway, a part of trans-European transport network. The current state of the Elbe waterway is characterized by its significant unreliability depending on navigational conditions. In the Czech Republic, *Methods of Effectiveness Evaluation of Investment in Waterways* is currently used as it also includes risk assessment. The article focuses on the comparison of risk assessment methods, thus the above-mentioned *Methods* and the empirical RIPRAN™ method. Both methods are demonstrated on a case study of a project connected to the development of waterway infrastructure, namely the most significant construction in terms of navigability of the Elbe from Děčín towards Germany. The aim of this article is to propose an adjustment of the current method of risk assessment of investment projects based on the results obtained by the comparison.

Keywords: RIPRAN™, risk analysis, waterways, risk assessment of investment.

1. Introduction

Risks are inevitable part of every project and in order to reach the desired outcome, one needs to take risks into consideration. The article deals with risk analysis of investment projects connected to the development of waterway infrastructure. The aim of this article is to compare qualitative risk assessment by *Methods of Effectiveness Evaluation of Investment in Waterways* and RIPRAN™ method. The risk assessment is performed on a case study dealing with the Děčín weir construction, which is the most significant construction in terms of ensuring the navigability of the Elbe from Děčín towards Germany, i.e. towards a maritime port.

2. Analysis of current situation

Water transport is one of the most ecological means of long-distance transportation. Another advantage is also the cost and rather large shipping capacity. However, it is not possible to make use of these advantages due to the present condition of waterways. According to the Transport Union of the Czech Republic, conditions of EU states waterways are of different quality. Almost all the states realize the importance of inland shipping as inseparable part of transport system, but, given the currently decreasing share of inland shipping in the overall increase of transportation, the states at the same time recognize the necessity to take measures to change this trend on state level. Transport policies of individual states focus on inter-modal transportation with more significant use of shipping, which is the reason they take part in ensuring suitable infrastructure. Programs for support and directing of inland shipping differ greatly in individual states as they proceed from local conditions and previous development. As European Court of Auditors (2015) presents, within the pursue of better effectiveness of inland water transport financing, EU states should prefer such projects that relate to the corridors, rivers and river segments as they are of the greatest benefit to the overall improvement of inland water transport.

In the Czech Republic, freight transport is used within the means of import, export, and inland relations as well. The total share of all realized transportations is however very small as it represents a little less than 1 % of the total volume of freight transport. The most influential factor regarding the current situation is the unreliability of navigational conditions due to the unfinished infrastructure of waterways. Water transport in the Czech Republic is economically favourable, but highly unreliable. The unreliability lies in the fact that the shipper cannot guarantee the required transport volume in scheduled time. The stated fact is a result of bad quality of waterways in the Czech Republic; the most suitable watercourses for shipping are the Elbe and the Vltava. With regard to the unstable navigational conditions on Czech waterways, new projects are not implemented and current transport volume is shifted elsewhere. One of the important factors is also quite obsolete watercraft which worsens the competitive ability of freight water transport and also limits the potential advantages regarding the environment.

The priorities of waterway infrastructure development are the Děčín weir on the Elbe-Vltava waterway and Přelouč weir, which should ensure the extension of navigability of the Elbe waterway to Pardubice port (The Transport Union, 2016).

The implementation of projects related to the waterway infrastructure development is connected to a great amount of risk that needs to be managed properly. The term ‘risk’ in relation to a project represents a chance that something influencing the aims of the project will occur. The risk includes the possibility of loss or profit, potentially some variation of planned or required outcomes as a consequence of uncertainty connected to particular way of conduct (Smith, Merna, Jobling, 2006).

[2] Corresponding author: zahorska.h@fce.vutbr.cz

According to (Kerzner,2009) risk is defined as follows: *"Risk has two primary components for a given events – a probability of occurrence of that event and impact (or consequence) of the event occurring. Both the probability and consequence must be considered in risk management. Risk constitutes a lack of knowledge of future events. Typically, future events that are favourable are called opportunities, whereas unfavourable events are called risks. Risks and opportunities may be uncorrelated or only partially correlated on a given project."*
Nowadays, risk management can be performed in accordance with International Project Management Association based on risk engineering which represents a techno-economic discipline dealing with the issues of risk. In certain cases 'positive risk' is mentioned, though it is not a correct term according to IPMA. From the point of view of risk engineering, risk management includes processes such as risk identification, risk analysis, risk assessment, risk treatment, risk re-examination and monitoring and communication and consultation of risk with involved parties. More detailed description of mentioned processes is stated by (Doležal et al., 2012).
In practice, many types of risk can occur; according to Fotr et al., 2011, it is for instance: technical-technological risk, manufacturing, economic, market, financial, credit, legislative, political, environmental or information risk, or an intervention of superior power.

3. Used methods

The assessment of projects related to the Czech Republic waterway infrastructure proceeds from *Methods of Effectiveness Evaluation of Investment in Waterways*, hereinafter referred to as the *Methods*. This document functions as a tool to assess the effectiveness of investment in waterways. One of its aims is to determine prerequisites, content and method to process the assessment of effectiveness of individual investment actions. Another aim is to introduce the authors to Cost-Benefit analysis (CBA) with reference to entry data that change in time and thus need to be updated on a regular basis. The authors furthermore focus on risk assessment of a project related to waterway infrastructure.
Such focus of risk assessment has, according to Žďánský et al. (2013), two main objectives:

- to ensure and prove that the project is suitable for financing (economic and financial literacy) even if some entry data and prerequisites are with regard to potential risk influence overestimated or underestimated,
- to assess if the identified risks related to project preparation and implementation are acceptable and whether there is no pitfall leading to the project's failure.

According to the *Methods*, the first step is the identification of risks, which must to the utmost degree represent independent variables. Next step is the division of risks into two groups, thus to the quantifiable risks and the other risks. The quantifiable risks are integral part of the CBA and are assessed by quantitative analysis. The other risks are assessed by qualitative analysis, which is always performed within the CBA if the overall costs of a project exceed 100 Mil CZK. Sensitivity analyses are included within the qualitative analysis. The discussed variables can be a part of the CBA and examined on the basis of sensitivity test. The testing deals with variables and uncertain prerequisites of investment plan and also with impact of their change on the resulting indicator. In this case, the influence of identified variables on determinative indicators EIRR, FIRR, ENPV, FNPV and BCR is assessed. The acceptability of a project should be conditioned by reaching the expected value of the indicators as calculated by source probability distributions, followed by a performance of usability analysis and its limits.
In practice and not only in waterway projects, a situation when quantitative division of risk probability is not applicable might occur. In such cases, qualitative risk assessment is used instead. These methods proceed from a relation defined by probability of risk occurrence and seriousness of its impact. To determine the probability of risk occurrence, a scoring method is used with probability ranked from 1 (least probable) to 5 (highly probable). Similar scoring is used for risk impact, with value 1 representing almost imperceptible consequences and maximum value 5 the catastrophic ones. The risk rate is then calculated by multiplying the probability of risk occurrence by risk impact (Žďánský, Forman, Kumpoštová, 2013).
RIPRAN™ is an empirical method developed by doc. Ing. Branislav Lacko, CSc., in order to support project risk analysis. The method is based on procedural conception of risk analysis. It understands risk analysis as a sequence of processes while each process has its own defined inputs, outputs and activities. These activities transform inputs to outputs when certain objectives are reached. The point of this method is to support systematic performance of risk analysis so as to reach quality processing and effective results in terms of risk management in time available, Doležal et al. (2012). This method takes account of TQM (Total Quality Management), i.e. philosophy of quality, includes processes ensuring the quality of risk analysis-related activities as specified by ČSN ISO 10006 and follows the requirements for risk management by PMI® and IPMA®.
By RIPRAN™ method, the performance of risk analysis is divided into five basic phases:

1. Risk analysis preparation,
2. identification of threats,
3. qualification of risks,
4. response to risks,
5. total assessment of riskiness of a project.

The aim of the first phase, i.e. risk analysis preparation, is to prepare all that is needed to perform the analysis by RIPRAN^{TM}. A schedule of the progress of analysis performance is worked out by beforehand chosen team whose task is also to decide what requisites and sources will be used within the analysis.
The second phase identifies the threats, dangers and various scenarios. However, validity and complexity of prepared sources must be ensured in the first place. Subsequently, a team discussion defines a list of threats and scenarios. A threat represents concrete manifestation of danger and the cause of scenario. Their relationship can be defined as cause and consequence. The output of the second phase is a list of pairs threat – scenario, with a list of risk factors included.
Qualification of risks is the third phase by RIPRAN^{TM}. Its objective is to classify the probability of scenario occurrence and impact rate, as well as to assess the risk rate as such. The required quantities can be assessed numerically or verbally, using beforehand negotiated assessment scales. The assessment of the probability of risk occurrence and its impact rate is based on a team discussion. The resulting value is a product of probability value and impact value. The last phase of risk classification is the division of risks by their significance into the minor risks that can be managed during the implementation of the project and the risks that are of great significance.
The proposal how to lower the risk to acceptable level is created during the fourth phase. Solutions for individual scenarios are once again proposed during a discussion. It is possible to reassess the risk rate with regard to precautions and thus take into account the costs related to the implementation of proposed measures.
Overall assessment of the project riskiness is done in the final phase, as well as the assessment of overall risk rate based on the established criteria. More information can be found at (Lacko, 1999).
Subsequently, risk monitoring and evaluation follows. In the case of more complicated projects, it is advisable to work out a comprehensive report describing risk management in detail.

4. Case Study

The case study deals with waterway infrastructure development and risks related to the issue. The authors further focus on the above-mentioned Děčín weir on the Elbe watercourse, which is 247 km long, but not navigable in its entirety. The Děčín weir represents the most important construction on the Elbe waterway in terms of ensuring its navigability and economic use. Given the fact that the Elbe represents the only one, yet at the same time insufficient access to the maritime port on water, the Elbe transport corridor is of key importance for Czech international trade. Both railway and road transport are on the brink of exceeding its effective capacity. Water transport, if functional, effectively lowers competitive market prices of shipping. During dry seasons, thus with insufficient navigability, freight transport is ceased, as well as recreational and passenger transportation. The lower reaches of the Elbe, stretching for approximately 41 kilometres from German borders to Ústí nad Labem-Střekov, represent the critical point. Navigation is due to low flow stopped for approximately three to six months a year.
The Děčín weir would ensure draught of 140 cm for 345 days per year and draught of 220 cm for 180 days per year. Moreover, the construction of the weir is related to an adjustment of navigational water duct below the weir, adjustments in the reservoir of the weir, operational facility, implementation of right-bank aquatic and terrestrial migration zone, controlling gauging station and small hydroelectric power station located on the right bank of the Elbe, as the water transport section of Transport Union states.
Earlier, the authors dealt with quantitative analysis of risks performed on the basis of the *Methods of Effectiveness Evaluation of Investment in Waterways* published by Czech Ministry of Transport. The main risks influencing the project were identified as the investment costs and number of shifted tonne-kilometres from road and rail transport to water. The main finding was the necessary number of shifted tonne-kilometres in terms of ensuring economic effectiveness of the project. The calculation was based on the net present value of the project using the interpolation method, resulting in the number of 17 364 thousands of tkm for inland transportation, and 63 943 thousands of tkm for cross-border transportation.
To perform a complex assessment of the project, this article focuses on determination and assessment of risks of the selected case study with the aid of verbal assessment in accordance with the *Methods*, followed by the empirical method RIPRAN^{TM}.
Qualitative assessment of risks by the *Methods* is shown in Table 1. The first step was the compilation of registry of risks respectively assigned with the probability of occurrence and severity of impact. The resulting indicator represents the risk rate, calculated as a product of stated factors. The most significant risks are those related to construction, exceeding of the budget, political risks, risk of postponing the construction of related synergetic infrastructure and risk of strategic decision.

Table 1
Risk assessment of the Děčín weir project by methods of effectiveness evaluation of investment in waterways

ID	Risks		Probability of risk occurrence	Severity of risk impacts	Risk rate
1	Construction-technological and project risks	Project documentation risks	3	3	9
		Construction risks	3	4	**12**
		Exceeding of the budget risks	3	4	**12**
		Locality risks	3	3	9
		Technology failure risks	2	4	8
2	Market risks	Demand risks	2	4	8
		Other market risks	2	3	6
3	External risks	Political risks	3	4	**12**
		Superior power risks	1	3	3
		Legislative / tax risks	2	2	4
		Postponing construction of related synergetic infrastructure	3	4	**12**
4	Operational risks	Equipment-related risks	3	3	9
		Human factor risks	2	2	4
		Safety risks	2	3	6
5	Strategic risks	Contractual risks	3	3	9
		Strategic decision risks	3	4	**12**

Source: author's processing

Qualitative assessment by RIPRAN^{TM} method is shown in Table 2. The same registry of risks is applied as in the previous case. Individual threats are assigned with probability of occurrence. Each threat includes scenarios that can happen with certain probability. Overall probability of the risk, its impact and value are based on such assessed threats. To complete the risk assessment, each scenario is paired with respective measure to eliminate its occurrence. The table below shows that exceeding of construction costs and wrong strategic decisions related to the project represent the most significant risks.

Given the five-degree assessment scale commonly used for qualitative risk analysis by the *Methods*, similar framework of 5 x 5 x 5 was chosen for the RIPRAN^{TM} so as to perform a comparison. Verbal assessment is done in accordance with recommended categories of risk probability, impact and value, ranging from very low to extremely high.

Table 2
*Risk assessment of the Děčín weir project by RIPRAN^{TM}**

ID	Threat	Threat PROB	ID	Scenario	Scenario PROB	Overall PROB	Impact	Risk value	Measure
1	Construction-technological and project risks	MP	1.1	Project change, prolonged negotiations etc.	MP	MP	MODI	MRV	Firm schedule creation and its observance, quality proposal creation
			1.2	Failed expectations of structural stability of construction, quality, deadline etc.	MP	MP	MODI	MRV	Qualified and verified contractor selection, quality proposal creation
			1.3	Exceeding of the construction costs	MP	MP	SI	**HRV**	Budget with reserve, contractual assurance, quality sources
			1.4	Unsuitable nature of land and its ownership, costs of land adjustment	MP	MP	MODI	MRV	Purchase of involved land, possible dispossession
			1.5	Failed technology during project realization and service life, etc.	LP	LP	SI	MRV	Implementation of system of quality check, technical supervision, quality proposal
2	Market risks	LP	2.1	Abrupt change of demand, erroneous demand estimation, etc.	LP	LP	SI	MRV	A written agreement with waterway users necessary before the realization of the project.
			2.2	Instability of exchange rate, inflation, interest rate	LP	LP	MODI	LRV	Contractual assurance
3	External risks	LP	3.1	Change in government resulting in project stoppage, supranational political risk	MP	LP	SI	MRV	Appropriate insurance
			3.2	Superior power (ecological disaster, war etc.)	VLP	VLP	SI	LRV	Appropriate insurance
			3.3	Legislative / tax changes (general change in law or tax legislation)	LP	LP	MODI	VLRV	Contractual assurance
			3.4	Construction postponing for synergetic infrastructure	MP	LP	SI	MRV	High-quality preparation, contractual assurance
4	Operational risks	MP	4.1	Equipment-related risk (more expensive materials, wrong lifespan estimation, wrong expectation of residual value)	MP	MP	MODI	MRV	High-quality preparation, quality proposal

ID	Threat	Threat PROB	ID	Scenario	Scenario PROB	Overall PROB	Impact	Risk value	Measure
			4.2	Human factor (failure to hire qualified workers, irreplaceability, human fault etc.)	LP	LP	MI	VLRV	System of double check, quality proposal
			4.3	Safety (non/wilful damage to construction)	LP	LP	MODI	LRV	Security service hire, quality proposal
5	Strategic risks	MP	5.1	Contractual risks (change in contract, violation of applicable legislation etc.)	MP	MP	SD	SHR	Contractual assurance with respective sanctions
			5.2	Wrong project-related strategic decision	MP	MP	SI	**HRV**	Strategic decisions made by a team of qualified professionals

Source: author's processing

Table 3
*Matrix for category assignment of risk value by RIPRAN™**

	SEVI	SI	MODI	MI	MINI
EHP	EHRV	EHRV	HRV	HRV	MRV
HP	EHRV	EHRV	HRV	MRV	NHR
MP	HRV	HRV	MRV	LRV	LRV
LP	HRV	MRV	LRV	VLRV	VLRV
VLP	MRV	LRV	LRV	VLRV	VLRV

Source: http://ripran.cz, author's processing

*Note: List of abbreviations
Probability: VLP - very low; LP - low; MP - medium; HP - high; EHP - extremely high
Impact: MINI - minimal; MI - minor; MODI - moderate; SI - significant; SEVI - severe
Risk value: VLRV - very low; LRV - low; MRV - medium; HRV - high, EHRV - extremely high.

5. Results

The authors focus on qualitative risk assessment comparison of commonly used method based on *Methods of Effectiveness Evaluation of Investment in Waterways* and RIPRAN™ method. Based on the performed analysis, the authors created a registry of risks for the Děčín weir project which later provided entry data for both considered methods.

Risk assessment by the *Methods* is primarily based on relations between probability of risk occurrence and severity of its impact. The assessment process is thus influenced by two factors that eventually determine the risk rate.

As for RIPRAN™ method, the first step is to determine the threats and probabilities of their occurrence followed by determination of scenarios, once again assigned with probability of their occurrence. The overall probability was determined on the basis of these two probabilities. Subsequently, the impact rate was determined. Risk values were taken from the matrix for category assignment of risk value. Each scenario was assigned with proper measure leading to risk neutralization.

If compared to the *Methods*, the empirical risk assessment by RIPRAN™ is more detailed, complex and laborious. The advantages are more precise results and the fact that this method encourages to search for measures that would decrease risk value. RIPRAN™ offers so-called 'type measures' that help to find concrete measures more easily. Its users gradually update the database of risks and measures and thus are step-by-step creating more and more complex instrument for project risk analysis.

Different results are obtained due to different approach of the used methods. According to the *Methods*, five significant risk factors were identified. As for RIPRAN™, only two significant risk factors were determined, both in accordance with outputs obtained by risk assessment by the *Methods*.

It is advisable to take measures to minimize risks related to exceeding of construction costs, such as creating the budget with reserves included, all based on quality and complex source material. There is also the option to conclude a contract with selected contractor, where the price would include all the costs connected to the realization of the project and would remain firm and definitive, with exception for extra works that cannot be expected.

It is necessary to eliminate strategic risks, mostly by choosing a qualified team of professionals eligible to make the required decisions. In general, the important measure is to conclude all the necessary contracts for most of the works in all stages of project service life.

6. Conclusion

The authors deal with project risk assessment focused on the development of waterway infrastructure on the Elbe, which represents the one and only access to maritime port by waterway. Given the fact that currently the Elbe waterway potential is not used due to unstable water flow, the authors focused on the most significant construction in terms of ensuring the navigability, thus the Děčín weir. In the first phase, registry of risks was worked out in order to perform a qualitative risk assessment comparison of commonly used method based on *Methods of Effectiveness Evaluation of Investment in Waterways* and RIPRAN^{TM} method.

Subsequently, an assessment of risk significance was carried out on the basis of the *Methods* and then on the basis of RIPRAN^{TM}. The most significant risks are those related to construction, i.e. exceeding of the budget, political risks, risk of postponing the construction of related synergetic infrastructure and risk of strategic decision. Exceeding of the budget and wrong strategic decisions are also significant risks as identified by RIPRAN^{TM}.

After applying both methods on a case study, a comparison was held, resulting in the fact that both methods identified exceeding of the budget and wrong strategic decision as the riskiest factors of the project. These risk must be handled carefully, though it is not advisable to underrate the other risks as well.

Eventually, the authors prefer RIPRAN^{TM} method, despite the fact that its risk assessment process is overall more demanding. Currently used risk assessment by the *Methods* is divided into qualitative and quantitative part. Quantitative assessment is being dealt with in more detail if compared to qualitative assessment. Therefore, the authors suggest to supplement qualitative risk assessment with RIPRAN^{TM} method. The main reason is its systematic approach to risk analysis and high-quality processing and effectiveness of the results.

Acknowledgements

This paper has been worked out under the project no. FAST-J-16-3778 Řízení rizik v předinvestiční fázi projektu s využitím moderních metod projektového řízení *(Risk management in pre-investment phase using modern methods of project management).*

References

Doležal, J.; Máchal, P.; Lacko, B. a kol. Projektový management podle IPMA. *(Project management according to IPMA).* 2., aktualiz. a dopl. vyd. Praha: Grada, 2012. Expert (Grada). ISBN 978-80-247-4275-5.

Evropský účetní dvůr. 2015. Zvláštní zpráva. Vnitrozemská vodní doprava v Evropě: od roku 2001 se významně nezvýšil podíl tohoto způsobu dopravy ani se nezlepšila splavnost. *(Inland Waterway Transport in Europe: No significant improvements in modal share and navigability conditions since 2001).* Lucembursko, 56 s. Available from Internet: <http://www.eca.europa.eu/Lists/ECADocuments/SR15_01/SR15_01_CS.pdf >.

Fotr, J.; Souček, I. Investiční rozhodování a řízení projektů: jak připravovat, financovat a hodnotit projekty, řídit jejich riziko a vytvářet portfolio projektů. *(Investment decisions and project management: How to prepare, finance and assess projects, manage their risks and create project portfolio).* 1. vyd. Praha: Grada, 2011, 408 s. ISBN 978-80-247-3293-0.

Kerzner, H. *Project management: a systems approach to planning, scheduling, and controlling.* 10th ed. Hoboken, N.J.: John Wiley, c2009, xxiv, 1094 p. ISBN 978-0-470-27870-3.

Lacko, B. 1999. RIPRAN: Metoda pro analýzu projektových rizik. *(RIPRAN: Method for project-related risk analysis).* Available from Internet: <http://ripran.cz/>.

Smith, N.J.; Merna, T.; Jobling, P. *Managing risk in construction projects.* 2nd ed. Malden, MA: Blackwell Pub., 2006, xii, 244 p. ISBN 9781405130127.

Svaz dopravy České republiky. *Koncepce vodní dopravy: Analytický dokument. (Water transport concept: Analytical document).* Ministerstvo dopravy České republiky, 2016, 90 s.

Svaz dopravy České republiky, Sekce vodní dopravy. Podrobné zhodnocení trendů vývoje vodní dopravy ve vazbě na legislativu EU. *(Detailed assessment of water transport trend development in relation to EU legislation).* 2015, 93 s. Available from Internet: <http://www.svazdopravy.cz/html/cz/in051026.pdf>.

Žďánský, D.; Forman, P.; Kumpoštová, A. Metodika hodnocení efektivnosti investic na vodních cestách. (*Methods of Effectiveness Evaluation of Investment in Waterways*). Ministerstvo dopravy České republiky, 2013, 61 p.

COMPARISON OF RAILWAY AND ROAD PASSENGER TRANSPORT IN ENERGY CONSUMPTION AND GHG PRODUCTION

Tomas Skrucany[1], Jan Ponicky[2], Martin Kendra[3], Jozef Gnap[4]
[1,2,3,4] *University of Zilina, Faculty of Operation and Economics of Transport and Communications, Zilina, Slovakia*

Abstract: This paper due to the simulation of energy consumption an GHG production of two different modes of regional passenger transport which use the same type of fuel – diesel. Simulation of an energy consumption in transport is often used due to satisfactory accuracy and cost efficiency. The simulation is not influenced by many surrounding factors which are acting during the measurements in real operation. Energy consumption and GHG production is calculated by using computer simulation. System "well to wheel" is used in evaluation.

Keywords: bus, energy consumption, GHG, production, simulation, train.

1. Introduction

Mobility is one of the most important human needs in this century. Average number of trips and the average traveled distance per man is constantly rising. Transport is becoming a very important element of human existence which has very negative impact on the environment by noise, vibration, accidents, areas needs, congestions and energy intensity (Kalina, T., Jurkovic, M., Grobarcikova, A. 2015, Dolinayova, A. 2011).
During the transportation process energy entering transforms in to the movement of vehicles which provide the required transfer of goods and people in the area. Therefore, the transport depends on the supply of energy (Camaj, J., Lalinská, J., Masek, J. 2015). Today transportation is largely dependent on oil, as the vast majority of vehicles are driven engines combusting petroleum products - hydrocarbon fuels.
Railway transport is representative mode of transport where most railway vehicles are now powered by electric traction motors, so the rate of dependence on oil is lower than previous modes. But the fact is that in most countries the electricity is produced through petroleum products or coal. All of these are non-renewable natural resources and their stocks have steadily declined.
Proper selection of traction in the railway transport can help implement the objectives of the White Book to minimize the energy consumption of transport and create a sustainable environmentally friendly mobility (Zitrický, V., Gašparík, J., Pečený, L. 2015, Kampf, R. et. al. 2015).

2. Model situation

In this case study we consider the transport along one chosen valley in Slovakia. There is a diesel railway track. Nowadays small trains run at this track regularly several times a day. There are two modes of passenger transport in the valley – train and bus. Tracks of both transport modes are situated along the river Rajcanka. This track connects Zilina (administrative capital city of northern territorial unit of Slovakia) and a small town Rajec situated in the southern part of valley with amenities for people lived in valley villages. Routing of track is North – South with distance of 21.3 km (Kendra, M., Babin, M., Barta, D. 2012.).
Difference of the altitudes between Zilina (340) and Rajec (450) causes the track slope which reaches the highest value 13‰, except a small hill before the railway station in Zilina where is the slope 17‰ but only on a short distance. Average slope between end stations is 5 ‰.
There are 12 stops (stations) on the track, Zilina is the first one on the beginning and the last one is Rajec at the end of the track. Between them there are 10 other stops. The highest track speed limit is 60 km/h but on some sections there are the speed limits only 50 or 40 km/h. Travelling time between the end stations is 37 minutes.
The average number of transported passengers for the year 2014 is 32 passengers on one train (Nedeliaková, E. et. al. 2014, Lizbetin, J. et. al. 2016).

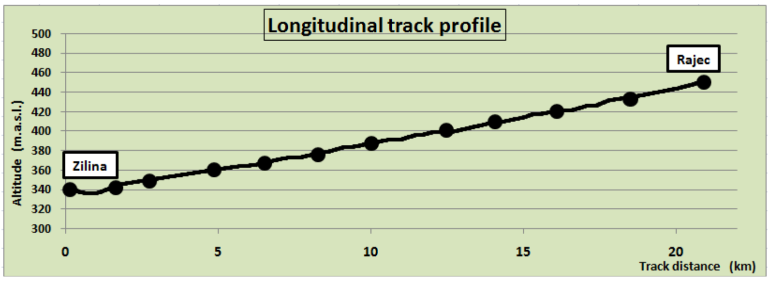


Fig. 1.
Elevation track profile with stations
Source: authors

[3] Corresponding author: martin.kendra@fpedas.uniza.sk

2.1. Vehicle technical parameters

Simulation of the energy consumption was done for a real bus and railway vehicles used in this valley. The bus Karosa C 954 was made by Karosa Vysoké Mýto from the year 2001 till 2006 (Liscak, S., Rievaj, V., Sulgan, M. 2008). The railway vehicle with series number 813-913 made by ZOS Zvolen as a reconstruction of an old diesel one unit railway vehicle with series number 810. ŽOS Zvolen has been making this diesel railway vehicle since 2007.

Table 1
Basic technical parameters of the vehicles

vehicle	***Train unit 813-913***	***Bus Karosa C 954***
drive arrangement	*1´A´ + 1’1’*	*-*
power system	*diesel*	*diesel*
power transmission	*hydromechanical*	*mechanical*
maximum speed	*90 km/h*	*105 km/h*
combustion engine	*MAN D 2876 LUE 21*	*Iveco Cursor F2 B*
design rate	*257 kW*	*228 kW*
tare weight	*39 t*	*10,8 t*
gross weight	*53 t*	*18 t*
vehicle length	*28 820 mm*	*11 990 mm*
number of seats	*78 + 5*	*49*
maximum number of standing passengers	*120*	*39*

Source: www.vlaky.net, www.kamim.sk

Fig. 2.
Vehicles (left: train 813-913, right: bus Karosa C 954)
Source: www.vlaky.net, www.kamim.sk

3. Calculation of energy consumption and emission production

Software Railway dynamics has been used to calculate the energy consumption of the train. This software was developed by Pavel Siman (Czech railways) and Jiri Petras (University of Pardubice) from Czech republic.
The power consumption of the train has been calculated on the basis of predefined and selected values on the defined route. The software works with imported maps and elevation profile of railway routes. Based on these defaults and selected parameters (locomotive type, train weight, train length, axle load, number and location of stops) power consumption was calculated in kWh. This software can be used to calculate energy consumption and operational or driving time of some arbitrary train on some arbitrary railway track. It is needed to import data of train and track for calculation (Klinko, M., Grenčík, J. 2008).
It is necessary to use the principle well-to-wheels for relevant comparison of the results for different types of consumed energy (Zamecník J., Jagelcak, J, Vrabel J. 2014, Knez, M. et. al. 2014).

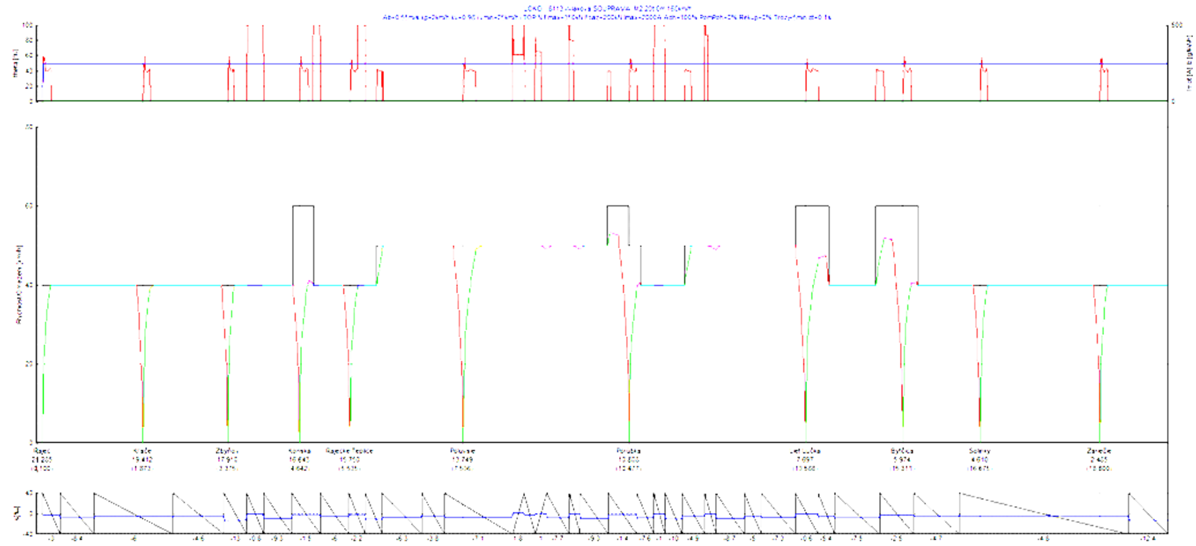


Fig. 3.
Output data from the software Railway dynamics
Source: author's software output (vlakova dynamika)

3.1. Standard EN 16258: 2012 and its using in calculations

This European Standard specifies general methodology for calculation and declaration of energy consumption and greenhouse gas emissions (GHG) in connection with any services (cargo, passengers or both). It specifies general principles, definitions, system boundaries, methods of calculation, allocation rules (allocation, assignment) and recommendations on information to support standardized, accurate, reliable and verifiable declarations regarding energy consumption and greenhouse gas emissions associated with any freight services. It also contains examples of these principles use.
The calculation for one given transport service must be performed using the following three main steps:
- Step 1: Identification of the various sections of the service;
- Step 2: Calculation of energy consumption and greenhouse gas emissions for each section;
- Step 3: Sum the results for each section (EN 16 258:2012).
The standard does not consider only the production of the secondary emissions and energy consumed during the combustion of the fuel (energy conversion from fuel to mechanical energy) but as well as primary, incurred in the extraction, production and distribution:

- e_w well-to-wheels energetic factor for defined fuel,
- g_w well-to-wheels emissions factor for defined fuel,
- e_t tank-to-wheels energetic factor for defined fuel,
- g_t tank-to-wheels emissions factor for defined fuel.

Well-to-wheels is "well on wheels" and also covered primary and secondary emissions and consumption. This factor is somewhere also called as LCA (life-cycle-analysis).
Tank-to-Wheels factor is thinking only of secondary emission and consumption.
This Standard specifies general methodology for calculation and declared value for the energetic factor and factor in greenhouse gas emissions must be selected in accordance with Annex A (EN 16 258:2012).
Emission gases are composed of several individual components (gas). Each of them have different chemical and physical properties, so they otherwise participate in environmental degradation. In order to compare emissions from different activities, fuels, vehicles where emissions have different impact, one representative unit used in the comparison must be designated. This is the CO_2 equivalent which is a measure of the impact of specific emissions and likens it to the impact of CO_2. The label is CO_2e (equivalent).

3.2. Energy consumption calculation

The calculation procedure for the diesel train using the software simulation is following. It is appropriate to use the factors and procedure form of the EN 16 258:2012 for diesel train. The amount of consumed fuel should be multiplied by energy factor for that fuel from Appendix A of the standard to calculate the total energy consumption.

$$E_{TF} = FC_V \,.\, e_W = [(E_{ME} \,.\, BSFC).\, 1/\rho_F \,].\, e_W \quad [MJ] \tag{1}$$

Where; E_{TF}: total energy consumed by diesel vehicles [MJ], FC_T :consumed fuel of vehicle [l , dm^3], E_{ME} :mechanical energy consumed by the movement of the train (train dynamics software result) [kWh], BSFC :break specific fuel

consumption of the vehicle engine [g/kWh], ρ_F :fuel (diesel) specific weight (density) [g/dm^3], e_W :energetic factor „wtw" for defined fuel [MJ/dm^3].
The calculation of consumed energy by the bus was easier. The fuel consumption data were provided to us from the bus carrier. He does fuel consumption measurements regularly, so the number of average fuel consumption is known. This value is exactly for one type buses operating in the valley with the corresponding capacity usage.

$$E_{TB} = FC_V \,.\, e_W = [(FC_A \,.\, L) / 100] \,.\, e_W \quad [MJ] \tag{2}$$

Where; E_{TB} :total energy consumed by bus [MJ], FC_V :fuel consumption of vehicle [l, dm^3], FC_A :average fuel consumption [l/100km], L :driven distance [km], e_W :energetic factor „wtw" for defined fuel [MJ/dm^3].

GHG production

For the GHG production calculation, the consumed amount of diesel fuel should be multiplied by an emission factor for that fuel from Appendix A of the EN standard.

$$G_{TF} = FC_V \,.\, g_W = [(E_{ME} \,.\, m_{Pe}).\ 1/\rho_F\ ].\ g_W\ [gCO_2e] \tag{3}$$

Where; G_{TF} :the total amount of emissions produced by diesel train [gCO_2e], g_W :emission factor for defined fuel [tCO_2e/MWh], for the buses the same principle

$$G_{TFB} = FC_V \,.\, g_W = [(FC_A \,.\, L) / 100] \,.\, g_W\ [gCO_2e] \tag{4}$$

Where; G_{TFB} :the total amount of emissions produced by bus [gCO_2e], g_W :emission factor for defined fuel [tCO_2e/MWh].
The basic units of MJ and gCO_2 were chosen for the calculation because they are declared units in the standard. However, for better comparison and expression, it is possible to expressed individual amounts in other units, for example GJ, KJ, tCO_2, $kgCO_2e$ or a combination of them, in the case of proportional expressing of quantities (see the evaluation) (Skrucany, T., Gnap, J. 2014, Skrucany, T. et al. 2015).

3.3. Evaluation

The calculation for this model study was done on the track in bidirectional ways, so one way down the hill and the other way up the hill. This elevation is seen in the energy consumption which is higher for uphill track, from Zilina to Rajec. Only the numbers as the results from transport in both directions are in the evaluation table and graphs.

Table 2
Final evaluation

State	Vehicle	Fuel consumption (L)	Total energy consumption (MJ)	Total emissions production (kgCO2e)	Passenger number	Energy per capita (MJ/person)	Emissions per capita (kgCO2e/person)
Full loaded	**train**	22.98	981.2	74.4	83	11.82	0.90
	bus	12.48	532.9	40.4	49	10.88	0.83
Real passenger number	**train**	17.72	756.6	57.4	32	23.65	1.79
	bus	11.76	502.2	38.1	26	19.31	1.47

Source: author´s calculation

Table of the final evaulation shows the advantage of the road transport vehicle – bus. There are very similar engines (performance and consumption) in both of the vehicles. However the railway track is not so difficult in slopes like the road, thus the railway vehicle does not reach the fuel consumtion lower than bus. It is caused by its tare weight – 39 t what is about 28 t more than cca 11 t of bus tare weight.

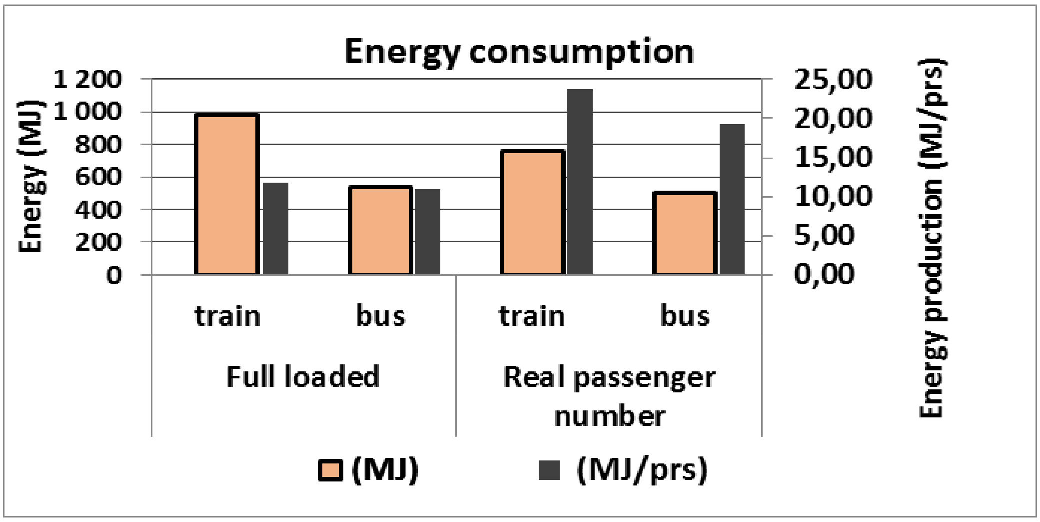


Fig. 4.
Evaluation of the energy consumption
Source: author´s calculation

The simulated fuel consumption of the diesel train was compared to the real consumption of this train operated on this track. This simulated result was validated because the simulation error was only -8%. So every consumption results were increased of the value 8% to be closer to the reality.
However, the diesel train reaches higher value of the real passenger number, thus it does not reach higher efficiency than the bus. As mentioned above, this fact is caused by the tare weight of the train. The total energy consumption of the bus represents only 54 - 66 % of the train consumption, according to the actual capacity usage. In the unit expression (MJ/prs) the difference is lower on account of higher capacity and passenger nr. values regardless of the effectiveness reached by the road vehicles.
Similar case as the energy consumption is the GHG production. The share between GHG production of vehicles is the same as the energy consumption because it was calculated according to the EN 16 258:2012 where the GHG production is a multiply of the fuel consumption and emission factor (Eq. 3, 4).

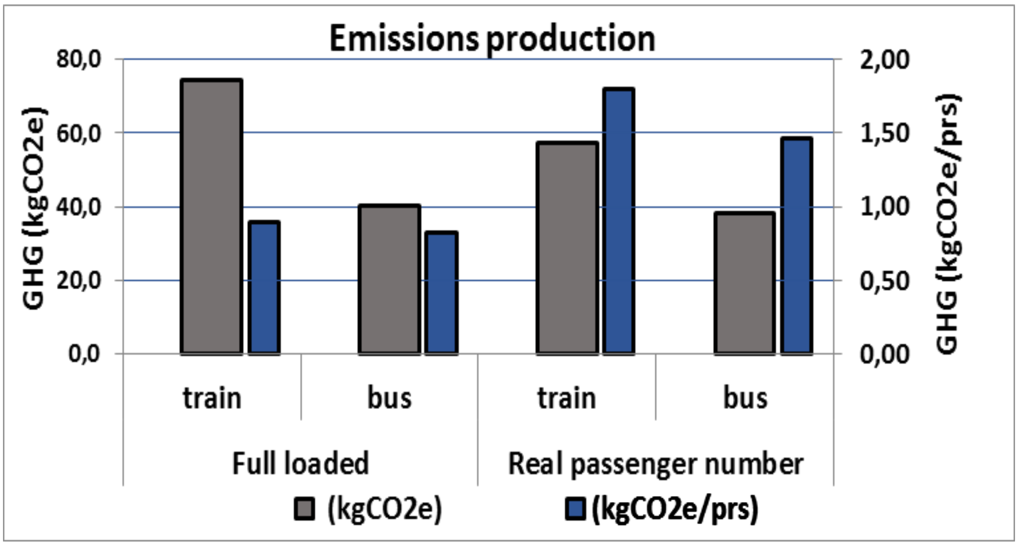


Fig. 5.
Evaluation of the GHG production
Source: author´s calculation

4. Conclusion

The results of this simulation do not determine which transport mode is better, greener or friendlier to the environment. It is not possible to do it, because the energy efficiency and GHG production is not dependent only on the fuel or energy consumption but also on the capacity usage. It is necessary to load the vehicles with the adequate number of passengers (suitable choice of the vehicle according to the transport flow). The transport efficiency is decreasing with the decreasing of actual capacity usage. So the coordination of the transport flow and vehicle operation is the step to greener transport.

Acknowledgements

This contribution/publication is the result of the project implementation:Centre of excellence for systems and services of intelligent transport II., ITMS 26220120050 supported by the Research & Development Operational Programme funded by the ERDF.
This paper is supported by the VEGA Agency by the Project 1/0095/16 "Assesment of the quality of connections on the transport network as a tool to enhance the competitiveness of public passenger transport system", that is solved at Faculty of Operation and Economics of Transport and Communications, University of Žilina

References

Camaj, J.; Lalinská, J.; Masek, J. 2015. The management of assessment and allocation of marshalling yards and designation their catchment areas, *Lecture notes in electrical engineering*, 349: 241-250.
Dolinayova, A. 2011. Factors and determinants of modal split in passenger transport. In: *Horizons of railway transport: scientific papers*, 2(1): 33-39.
European standard EN 16 258:2012. Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers).
Kalina, T.; Jurkovic, M.; Grobarcikova, A. 2015. LNG - Great opportunity for the inland water transport. In *Proceedings of the Transport means 2015 19th international scientific conference*, 489-492.
Kamim 2016. Autobusy Karosa od Sodomku po Citelis. Available from Internet: <http://www.kamim.sk>.
Kampf, R.; Stopka, O.; Bartuška, L.; Zeman, K. 2015. Circulation of vehicles as an important parameter of public transport efficiency. In *Proceedings of the Transport means 2015 19th international scientific conference*, 143-146.
Kendra, M.; Babin, M.; Barta, D. 2012. Changes of the infrastructure and operation parameters of a railway line and their impact to the track capacity and the volume of transported goods, *Procedia Social and Behavioral Sciences,* l(48): 743-752.
Klinko, M., Grenčík, J. 2008. Tilting body vehicles on Slovak railways - potential for use and parameters to be considered In: *Communications* : scientific letters of the University of Zilina. Vol. 10, No. 3 (2008), 45-49
Knez, M.; Muneerb, T.; Jereba, J.; Cullinaneb, K. 2014. The estimation of a driving cycle for Celje and a comparison to other European cities, *Sustainable cities and society,* 11: 56-60.
Liscak, S.; Rievaj, V.; Sulgan, M. 2008. Vehicle's technical condition and emission, *Eksploatacja I niezawodnosc-maintenance and reliability*, 1: 61-63.
Lizbetin, J.; Vejs, P.; Stopka, O.; Cempírek, V. 2016. The significance of dynamic detection of the railway vehicles weight, *Nase More*, 63(3): 156-160.
Nedeliaková, E. et. al. 2014. Services in railway passenger transport and its evaluation by dynamic models. In *Proceedings of the Transport means 2014 18th international scientific conference*, 227-230.
Skrucany, T.; Gnap, J. 2014. Energy intensity and greenhouse gases production of the road and rail Cargo transport using a software in simulate the energy consumption of a train. In *Proceedings of the Telematics - support of transport 14th international conference on Transport systems telematics, TST 2014*, 263-272.
Skrucany, T.; Kendra, M.; Sarkan, B.; Jozef Gnap, J. 2015. Software simulation of an energy consumption and GHG production in transport, *Communications in Computer and Information Science,* 531:151-160.
Vlaky 2016. Motorové jednotky na našich kolejích: řada 813. Available from Internet: <http://www.vlaky.net>.
Zamecník J.; Jagelcak, J.; Vrabel, J. 2014. Influence of drive style on petrol consumption for low-volume petrol engine. In: *MMK 2014*: 15.-19.12.2014, Hradec Králové, Czech republic- Hradec Králové: MAGNANIMITAS. 3211-3220.
Zitrický, V.; Gašparík, J.; Pečený, L. 2015. The methodology of rating quality standards in the regional passenger transport, *Transport Problems = Problemy Transportu* : *international scientific journal,* 10: 59-72.

OPTIMISATION OF RAIL TRAFFIC FLOW DURING MAINTENANCE ON INFRASTRUCTURE

Jelena Aksentijević[1], Andreas Schöbel[2]
[1,2] OpenTrack Railway Technology GmbH, Kaasgrabengasse 19/8, 1190 Vienna, Austria

Abstract: Within the by H2020 founded project DESTination Rail, a task is dedicated to the development of a tool for rail traffic flow optimization in terms of maintenance work. On a single track line priority is set for as much work as possible to be done in one time slot between two trains. Sometimes, the timetable is even modified to allow more efficient maintenance work. On a double track line all traffic has to run over the remaining track, where typically a slow speed zone is established to protect working staff. For this bottleneck section, it is very important to have an efficient usage of capacity. Therefore, it is necessary to optimize the speed profile of approaching trains to let them pass the bottleneck section exactly at the allowed speed limit to keep occupation time as short as possible.

Keywords: Kronecker algebra, rail traffic flow optimization, rescheduling.

1. Introduction

Rail infrastructure managers are responsible for safety measures and investments within the infrastructure network. Their choices are usually not only based on poor data availability, but also on the visual assessment of infrastructure conditions. Unfortunately, there is enough evidence that visual analysis shows indications for needed actions very late in the deterioration infrastructure process, or not at all. Consequently, the objective of the EU project DESTination RAIL [1] is development of a Decision Support Tool, which relies on reliable data, for rational decision making of infrastructure managers to offer safer, reliable and efficient rail infrastructure. The idea of developing a flexible decision support tool enables possibilities to use it across a range of asset classes, such as: bridges, earthworks, tunnels, switches, and tracks. Rail traffic flow optimization represents a priority in cases of restricted network availability. It is a part of a four-step process, which infrastructure managers face in their decision-making processes. Namely, location and identification of risky assets before they fail, then real-time safety assessment of existing infrastructure; furthermore, evaluation of safety and assignment of scarce resources and finally, choosing the optimal rehabilitation techniques. Using Kronecker algebra, which showed good results in dealing with bottlenecks [2] a case study for optimization of rail traffic flow during maintenance work at Boyne viaduct in Ireland (Fig.1) was conducted.

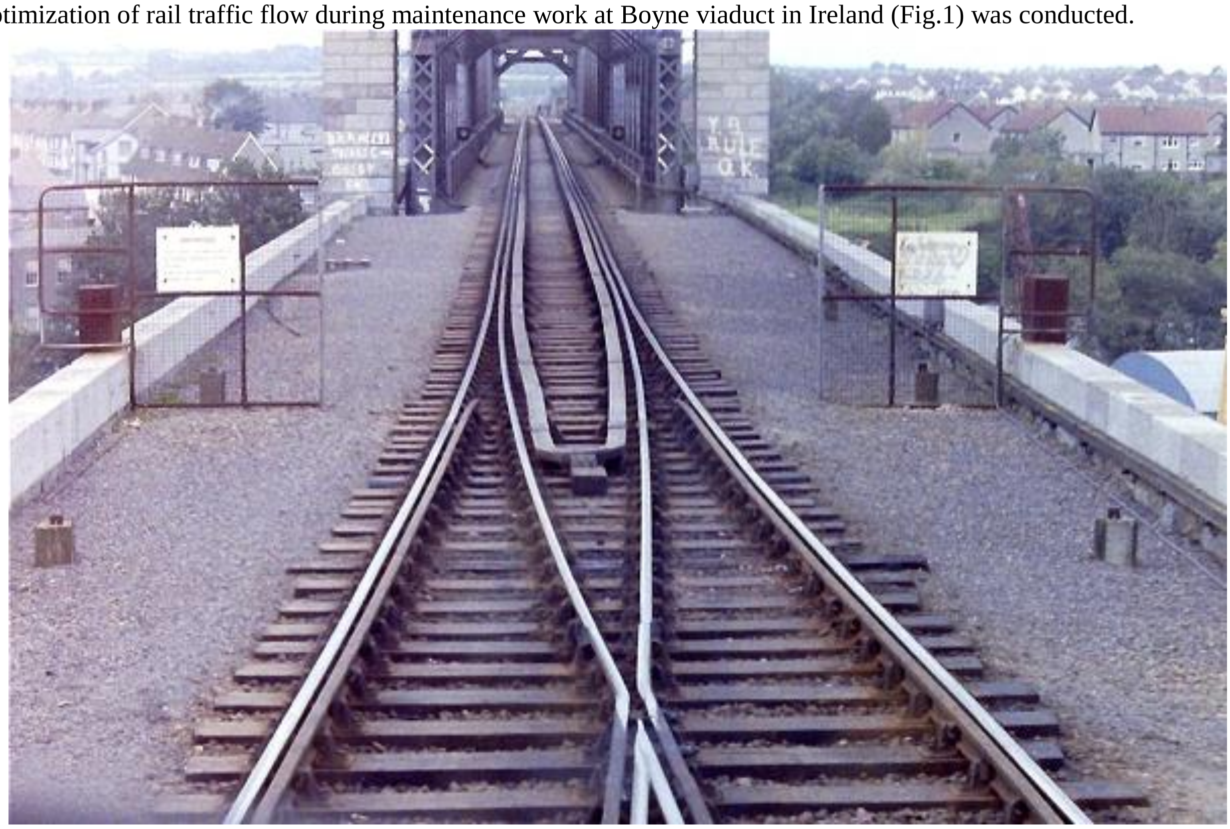


Fig. 1.
Boyne viaduct, Irish Rail
Source: http://www.geograph.ie/photo/2300019

[1] Corresponding author: jelena.aksentijevic@opentrack.at

2. Rail traffic flow optimization tool

The focus of this paper lays in the fourth stage of the flow optimization, namely, the analysis of the possible infrastructure maintenance or renewal strategies. Application of microscopic simulation of railway operations based upon a physical and mathematical model of the railway system is the state of the art in railway traffic operations. Such tools output indicators for the operational performance (e.g. delays). These have a series shortcomings, most notably that optimisation is typically predefined by the user of the tool and introduced into the simulation. This common practice allows the user to find solutions for bottleneck management and planning of maintenance work. However, it often misses the opportunity to find the optimum solution. It is, therefore, not fully capable of solving dispatching questions or handling headway conflicts. To close this gap in future railway operation with increased traffic flow, algorithms have to be applied which consider all train runs at the same time. Within DESTination RAIL, microscopic simulation tool will both improve traffic flow and assess the impact of maintenance and renewal proposals.

3. Dataflow Model

The input data used for the traffic flow optimization tool is defined by two components: first, the current characteristics of the rail system will be supplied. Second, the infrastructure manager will indicate a desired assessment of a change in the network. Those two components will be merged using simulation tool OpenTrack [3] for the visualization of the data, and further processed into the concrete syntax of the input files needed by the optimization tool. This workflow is shown in the Figure 2:

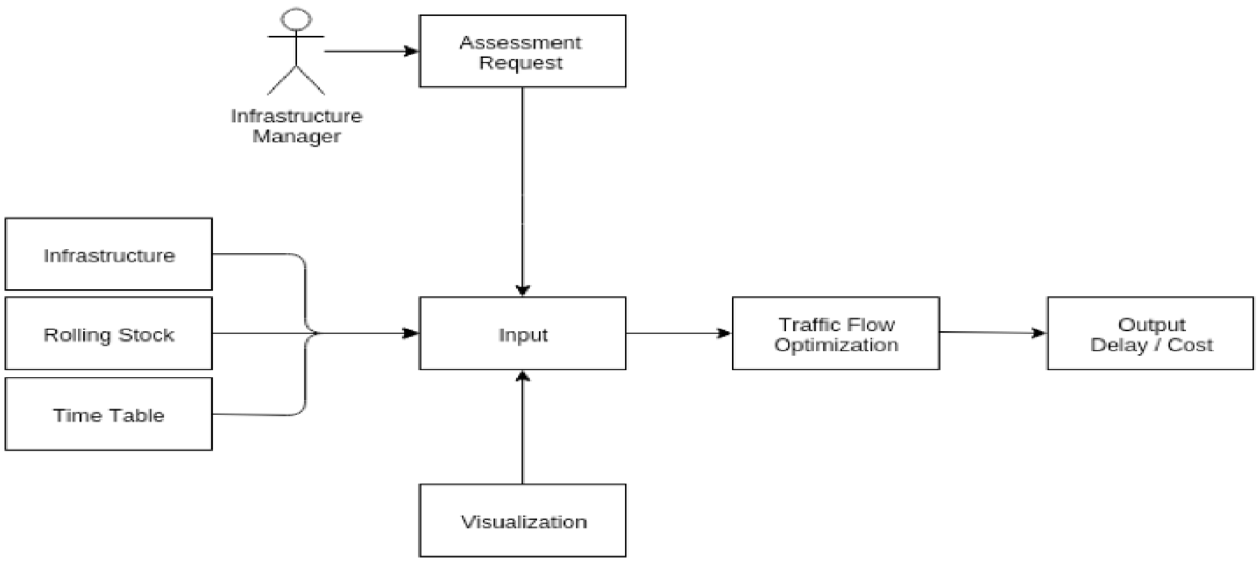


Fig. 2.
Dataflow model
Source: www.destinationrail.eu

As it can be seen in the Figure 2, in order for Traffic Flow Optimization process relying on Kronecker algebra approach to deliver Output data, a number of input data is needed. First, and most important, is the set of Infrastructure, Rolling Stock and Timetable characteristics, which represent the base of future calculations. Secondly, infrastructure manager's identification and assessment of consequences of whether it be restricted availability of infrastructure assets, of operational incidents.

4. Data required

The level of details and accuracy directly influences the quality of output. As it can be seen from the Figure 1, two types of sources are used for a complete input data. First represents the crucial elements for the operation of the railway network. Second, the desired change in the network must be indicated. These two components will be merged using lightweight visualization tool before being further processed into the concrete syntax.

4.1. Input Data: Infrastructure, Rolling Stock and Timetable

Infrastructure data comprises information about tracks and operation control points, as well as all related information. The rolling stock data concerns physical characteristics of trains that are part of the traffic system under consideration. The timetable data provides information about planned train routes and their associated time schedules.

4.2. Input Data: Infrastructure Manager Assessment Request

Infrastructure manager can analyze different possible changes in network. First, consequences of restricted availability of infrastructure assets can be assessed. The aim of this is to reduce the impact of restricted availability of infrastructure assets. The incident can be maintenance work on a given track section, which leads to a reduced speed limit for that section or on the neighbouring track, as a protection measure for the staff. Furthermore, consequences of operational incident can be assessed. An interruption event can be a result of the broken down train or unavailability of the track section due to external factors, for example, flooding of a bridge. For both above mentioned cases, the following data has to be provided by the infrastructure manager:

- affected track or track section (reference: infrastructure & timetable input)
- speed change [km/h]
- time period (begin [hh:mm:ss] – end [hh:mm:ss])
- thresholds for delays of affected trains [hh:mm:ss]
- costs of delay per minute for different train categories (regional, intercity, freight) and for the passenger transport information about differences in costs depending on the day of the week.

Finally, there is a possibility of assessment of benefits from infrastructure enhancement. Examples of infrastructure enhancement can be the construction of an additional cross over on a highly frequented line or construction of an additional bridge. The following data has to be specified by the infrastructure manager:

- location of the planned section and connections to existing tracks (reference: infrastructure input [track::id] and position on the track [meters])
- length of the planned section [meters]
- speed restriction on the selected section [km/h]
- gradient on the selected section (if changed) [‰]
- set of affected trains (reference: timetable)
- costs of delay per minute for different train categories (regional, intercity, freight) and for the passenger transport information about differences in costs depending on the day of the week.

5. Use case of Irish Rail

Within DESTination Rail project, Irish Rail network, more precisely, the Boyne Viaduct (shown in Fig.1.), is used as a case study for the development and analysis of a rail traffic optimization tool. OpenTrack [3], a software for simulation of railway operations, offered visualization of railML input data by converting them into graphic representation of infrastructure (Fig.3), where Boyne Viaduct represents the test (maintenance work) zone between Drogheda and Dundalk, obtained from the Network Statement of the Irish Rail [4].

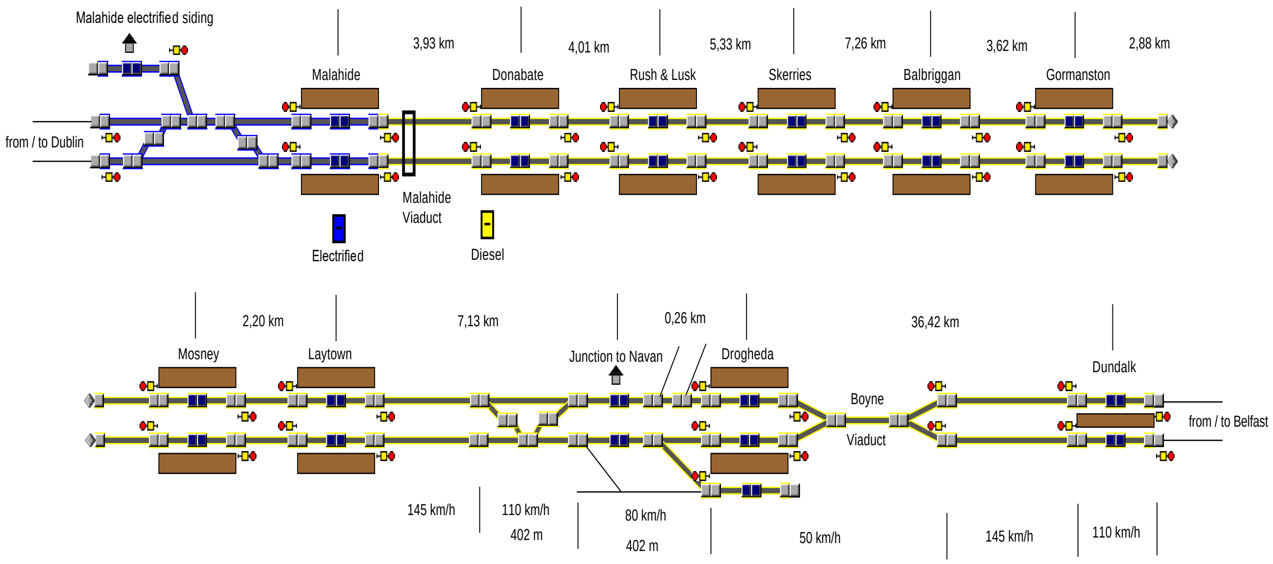


Fig. 3.
Infrastructure: Boyne Viaduct
Source: www.destinationrail.eu

Rolling Stock data includes IC and Cargo trains using class 201 and DART traveling only to Malahide. Finally, timetable data (only for passenger trains) is shown in Fig. 4.

		MON-SAT	MON-SAT	MON-SAT	MON-SAT	FRI ONLY	MON-SAT	MON-SAT	MON-SAT	MON-SAT
DUBLIN Connolly	Dep	07.35	09.30	11.20	13.20	14.45	15.20	16.50	18.50	20.50
DROGHEDA MacBride	Dep	08.09	10.06	11.56	13.56	15.27	15.54	. .	19.28	21.28
DUNDALK Clarke	Dep	08.31	10.28	12.18	14.18	15.52	16.16	17.48	19.50	21.50

DUNDALK Clarke	Dep	06.59	08.00	09.15	11.47	13.47	15.20	16.05	17.20	19.20	21.20
DROGHEDA MacBride	Dep	07.20	08.22	. . . .	12.08	14.08	15.41	16.30	17.41	19.41	21.41
DUBLIN Connolly	Arr	08.18	09.00	10.05	12.40	14.40	16.20	17.14	18.15*	20.15*	22.15*

Fig. 4.
Timetable: DUBLIN-DOGHEDA-DUNDALK
Source: www.destinationrail.eu

Figure 5 shows a train graph, whereas in Figure 6 the optimized train run is displayed, both presenting an output of Kronecker algebra use. Clearly, the optimized train runs do not run at the maximum allowed speed, since Kronecker algebra approach offers solutions for avoidance of deadlocks. Further information and detailed outline of the function of the Kronecker algebra can be find in [5]. The solution offered by this approach shows the optimal way for passing bottleneck sections at exactly allowed speed and given time, in order to keep the occupation time at the given section as short as possible without unnecessary energy consumption due to, for example, braking for signal.

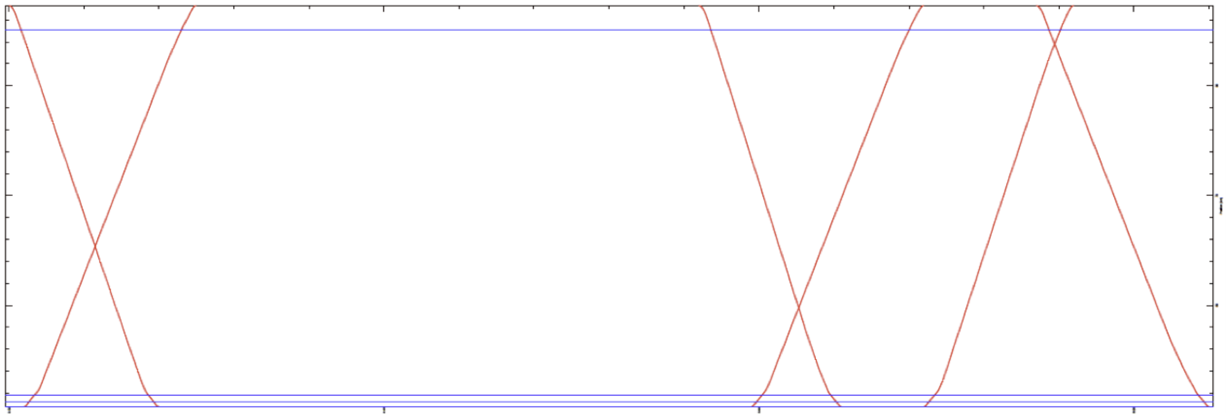


Fig. 5.
Output from Kronecker Algebra: Train Graph
Source: www.destinationrail.eu

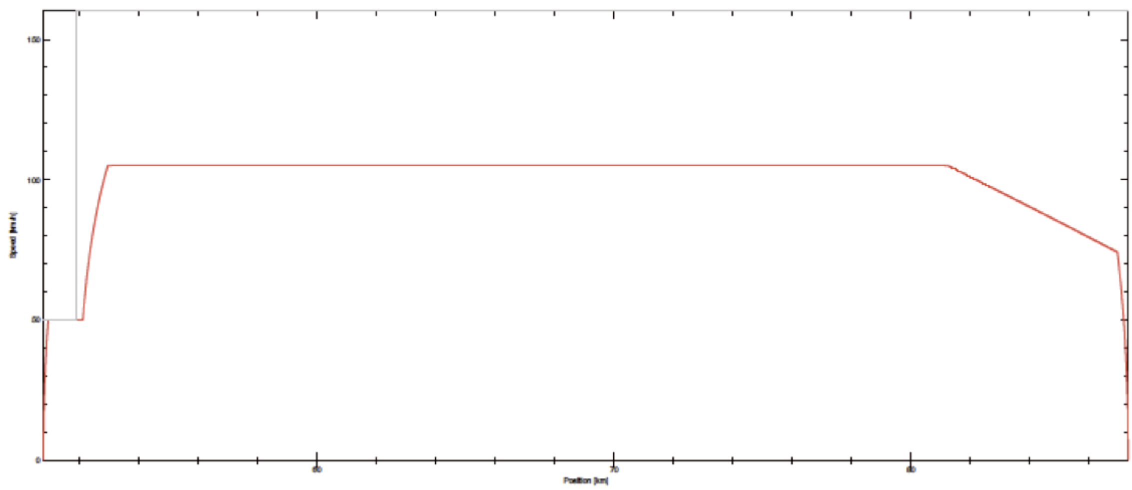


Fig. 6.
Output from Kronecker Algebra: Optimised Train Run
Source: www.destinationrail.eu

Finally, Figure 7 lists delays and the energy consumption for all trains involved.

- T1 Train1 108000 400000 213 8 210 160 0.85 50786 87318
- T2 Train2 108000 400000 213 8 210 160 0.85 50786 87318
- T3 Train3 108000 400000 213 8 210 160 0.85 50786 87318
- T4 Train4 108000 400000 213 8 210 160 0.85 87318 50786
- T5 Train5 108000 400000 213 8 210 160 0.85 87318 50786
- Structure of output: ID / TrainID / Engine mass / Trailer mass / Train length / No. of wagons / Used engine / max. speed / recuperation rate / start time / stop time

- Train 1 Result 1 of 1 Energy demand: 256.6 Demand complete: 256.6 kWh
- Train 2 Result 1 of 1 Energy demand: 230.1 Demand complete: 486.7 kWh
- Train 3 Result 1 of 1 Energy demand: 256.6 Demand complete: 743.3 kWh
- Train 4 Result 1 of 1 Energy demand: 254.8 Demand complete: 998.1 kWh
- Train 5 Result 1 of 1 Energy demand: 254.8 Demand complete: 1252.9 kWh

- New minimum found: 1252.9

Fig. 7.
Output from Kornecker Algebra: Delay and Energy Consumption
Source: www.destinationrail.eu

6. Conclusion

In conclusion, development of rail traffic flow optimization tool enables infrastructure managers to base their decisions on reliable data without output surprises. In other words, optimal solutions will ensure high level of efficient use of, very often scarce, resources and optimal process flow. This tool will enable one to set clear priorities based on reliable date and ensure minimal loss of operations, and more importantly, energy.

Acknowledgements

DESTination RAIL project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement No 636285.

References

Destination Rail Project. Available from Internet: <http://www.destinationrail.eu>.

Mittermayr, R.; Blieberger, J.; Schöbel, A. 2012. Kronecker algebra-based deadlock analysis for railway systems, *Traffic Planning*, 24(5): 359-369.

Network Statement of Irish Rail. Available from Internet: <http://www.irishrail.ie/media/ie_2016_network_statement_2904.pdf>.

OpenTrack Railway Technology. Available from Internet: <http://www.opentrack.at>.

Volcic, M. 2014. *Energy-efficient Optimization of Railway Operation: An Algorithm on Kronecker Algebra*. Dissertation: Vienna University of Technology.

MOBILITY STRATEGIES AND ACTIONS TO REDUCE CARBON FOOTPRINT IN ATLANTIC AREA TERRITORIES

Dominique Breuil[1], Lobna Haouari[2], Véronique Seel[3]
[1,3] EIGSI, 17000, La Rochelle, France
[2] EIGSICA, Casablanca, 20000, Morocco

Abstract: Based on the outcomes of two Atlantic Area (AA) Interreg projects like Climatlantic and REPUTE, the presentation focuses on mobility actions adapted to the specificities of rural and peri urban territories in order to reduce related carbon footprint and to analyze the transferability of these recommendations on Mobility in other similar areas.
The general approach was to compare possible strategies/actions envisaged by local authorities and behavior/expectations of citizens regarding transport modes in order to point out convergences (and divergences). The analysis is based on the exploitation of surveys done:

- for local authorities, by interviews of 52 transport policy makers of several cities of the AA, concerning the best mobility strategies and actions for reducing carbon footprint
- for citizens, by questioning 3000 travelers living in the area on their habits ; this lead to sort 8 socio-types regarding mobility behavior, each having their own specificities..

The merging of these two approaches gave the opportunity to identify which strategies and actions could meet the travelers' expectations.

Keywords: carbon footprint reduction, demand driven mobility, policy making.

1. Introduction

Climate change has become a major concern for the future of Europe. This applies both to efforts to mitigate climate change by tackling the growth in greenhouse gas emissions and the need for measures to adapt to the impacts of climate change.
Together these challenges will impact on the development of Europe's economies and societies over the coming years. The different regions of the Atlantic Area will not be concerned in the same way with these challenges due to the wide diversity of productive structures across the Atlantic Area, more sectorial specialisations in the southern countries and more diversification in the northern part of the Atlantic Area.
The Atlantic Area is likely to be more vulnerable to climate change than other European regions. Apart from the consequences of climate change, the transfer of population towards coastal zones, unemployment rates and economic issues will have a direct relationship with transport organisation and mobility demand. The range of the impacts on transport is quite large, directly or indirectly, from the eventual reductions of land and increase of flood risks to population moves and agricultural production changes. The pillars of the CLIMATLANTIC project {CLIM 2013) aimed at fostering the development of strategies at regional and local level to reduce the carbon footprint in the European Atlantic Area ; the "Mobility" pillar activities were focused on the complex and very diverse mobility situations of the various territories of AA.
Mobility for passengers and goods was considered as a multilevel problem which requires coordinated and coherent solutions from the bottom level (ex cities) to the top level which is has no real existence. However, several institutions like Conference of Atlantic Arc cities or Conference of Peripheric Maritime Regions propose orientations or directives.
Usually, decisions concerning mobility are taken at intermediate levels, by regional authorities and urban communities (group of several cities). For these, several tools and methodologies exist in order to help local authorities when improving mobility with regards to Climate criteria, for instance Sustainable Urban Mobility Plans (SUMP 2015). But these tools are focused on local actions then the resulting local optimisations suffer sometimes some lack of coordination and some incoherencies between neighbouring or similar cities/regions.
In order to avoid such situations, the Mobility Pillar developed a "meso" approach based on the combination on different points of view regarding actions to reduce carbon footprint:

- The identification of the specificities of the different type of territories along AA
- The possible mobility strategies and types of actions
- The behaviours of travellers in the AA

The objective was to compare the actions envisaged by decision makers and the expectation of travellers. This approach (eg criteria, analysis,…) was developed in coherence with the 3 other CLIMATLANTIC pillars dealing with energy, land management and behaviour change

[2] Corresponding author: dominique.breuil@eigsi.fr

2. Specificities of AA territories

From the territorial structure point of view, the AA area integrates several regions with different urban typologies that in the coming years will not have the same objectives or position with regards to the major topics that influence both urban settlement and transport demand of passengers and goods, namely Demography, Urbanization and Economy.
Thus it would not appear reasonable to have identical recommendations or strategies for all the regions. However, it will not be possible to determine which strategy is optimal for each region or even sub-region. In this case, the approach has been to identify the most significant contexts in which each AA territory can recognize its own situation.
The recent ESPON projects (DEMIFER, FOCI and EDORA cf ESPON 2013) clearly show the differences between AA regions regarding several criteria. The report on metropolitan areas in Europe (MAE 2011) proposes a complementary approach on the functions performed by cities and agglomerations at the regional or local level in order to organise and control the various social systems that are represented in their territory. Six types of function may be identified:

- Living facilities: housing, shops, crafts, etc.
- Social facilities: transport, health, etc.
- Administration: politics, law& courts, police, etc.
- Innovation & prospective: research, education, innovation, etc.
- Culture: arts, sports, tourism, etc.
- Economy: industries, services, etc.

If these functions are combined with the demographic and economic parameters (especially employment), four main types of regions can be defined representing the various structural situations that can be found in the AA regions regarding both territorial organisation and mobility in terms of accessibility to the main centres for daily work or shopping

- predominantly urban, dominated by a metropolitan area
- group of equivalent medium sized cities grouped in a polycentric network,
- medium sized city with smaller satellites
- low demographic density (predominantly rural)

3. Mobility strategies for AA

The objective of this global level approach is to focus on recommendations which should be significant for AA territories and decision makers. These have been consolidated by interviews with politicians in charge of mobility in several cities.

3.1. Strategic domains

The following mobility domains have been identified as the most susceptible to be the theatre of local authorities' decisions applicable in each of the 4 types of territories based CIVITAS approaches (CIVITAS 2016):

- Clean fuels and vehicles grouping all actions in favour of the development of more environmental friendly transport resources
- Mobility management encompassing decisions which tend to organise mobility of citizens and goods, from personalised travel plans to integrated pricing. These decisions are also linked to development strategies of the Territory and of its main components (ex cities)
- Alternative mobility usages or modes which can be described as less car intensive life style or "soft measures". This domain encompasses activities dedicated to the behaviour changes from stakeholders
- Demand management: this covers all actions which aim to optimise the demand response
- Collective passengers transport on several aspects like quality of services, travel information, network development, intermodality, ticketing. Although this is clearly people oriented, similar actions could be developed for goods in the future, especially with the development of Internet of Things or freight mixity
- Logistics : this deals with the actions aiming to improve the distribution of goods over an area, urban, peri urban or regional. They can be related tofleet management, route planning, storage facilities…..
- Mobility information systems which covers all actions related to information technologies, from mobile exchange to operation exploitation software
- Infrastructures : covers all actions related to the design and implementation of any kind of infrastructure not taken into account in previous topics. This domain is strongly linked to Land Planning actions.

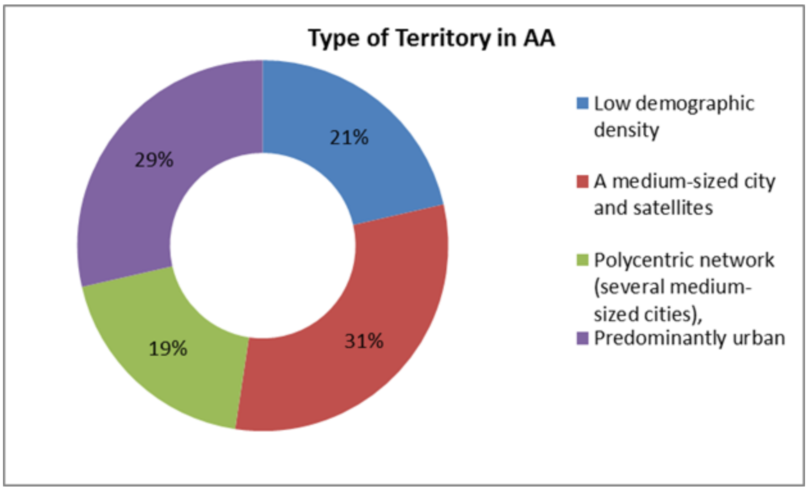


Fig. 1.
Split of interviews

21 mobility relevant strategies have been identified to reduce carbon footprint on AA; the list is in fig 2 below. Obviously, each action strategy which could be envisaged is likely to concern many mobility domains. Several types of actions were associated to each strategy ; the list of actions could be increased by respondents. For instance the strategy "*To develop Collective Transport network homogenously with land planning*" was split in:

- *Traversability of AA from/to hubs, ports, gates*
- *Capillarity inside territories*
- *Interoperability*
- *Intermodality between regions, specially with rail*
- *Others….*

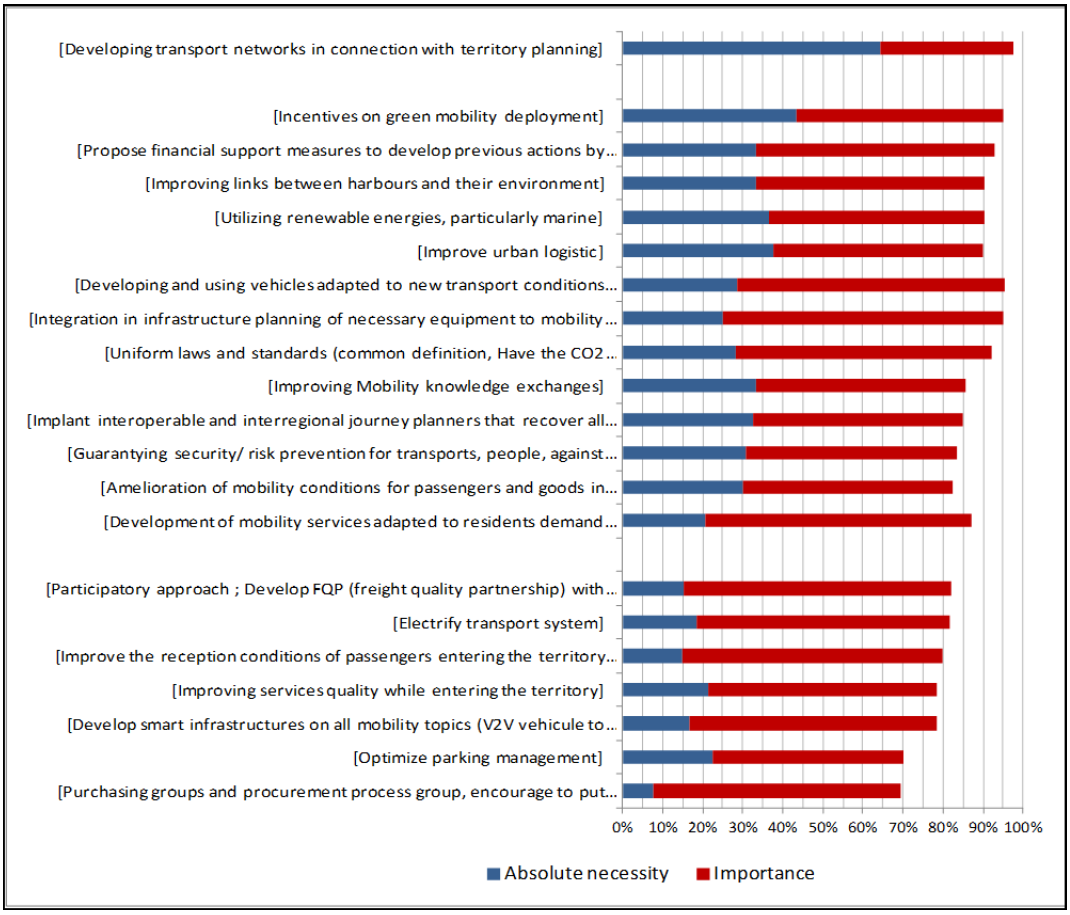


Fig. 2.
Classification of mobility Factors

3.2. Mobility factors in AA

In order to determine priorities from the decision makers, 52 stakeholders were interviewed and the envisaged time scale was 2025.
The rating had 4 positions (*No importance, low contribution, Importance or Absolute necessity*)for each of the actions.
Among the 21 actions and strategies, almost all of them are highly rated in terms of contribution for carbon footprint reduction, showing the difficulty for decision makers to choose between all this strategies and actions.
However all opinions were not identical and some "controversies" appeared between interviews due to the ratio between the rating of an action as an « absolute necessity » and as a « low contribution/no importance » contribution. Among the global result and the weight of the "absolute necessity" into the answers of importance, we could also observe a split between actions with an antagonist position between responsible of transport thinking that this action is an absolute necessity and others rating the contribution as "low" or "no importance".
Regarding mid term (by 2025), the "Developing transport networks in connection with territory planning" action clearly stands out, rated by about 65% of responsible of transport to be "an absolute necessity". 33% rated this action as "important"
6 strategies and related actions are approved by quite all respondents rated between 95% and 90%[3] as "an absolute necessity" or "important"; with no controversies. They are dealing with Infrastructures and land planning domain, Finance instruments, Clean fuels and vehicles domain, logistics and mobility management.
4 strategies and actions highly rated in terms of contribution by all responsible of transport might be subject of "controversies"
They essentially deals with Demand management and Managerial position such as

- "Development of mobility services adapted to residents demand (elderlies, suburbs, low density territories…) for example TAD"
- "Amelioration of mobility conditions for passengers and goods in interregional rails trips (comfort, frequency, access…)"

7 strategies and actions are both subject of "controversies" AND with relative low contribution although the "lowest" one is rated at 70% as important. To enhance the relevance of the actions with AA specificities, they were grouped in 3 categories,

- Strategies and actions strongly linked to AA, Those actions are mainly related to marine (Altlantic) proximity and European entry.
- Strategies and actions which are influenced by AA situation but could be found in other European areas, like tourism
- Strategies and actions which can improve mobility in AA territories similarly as in other areas

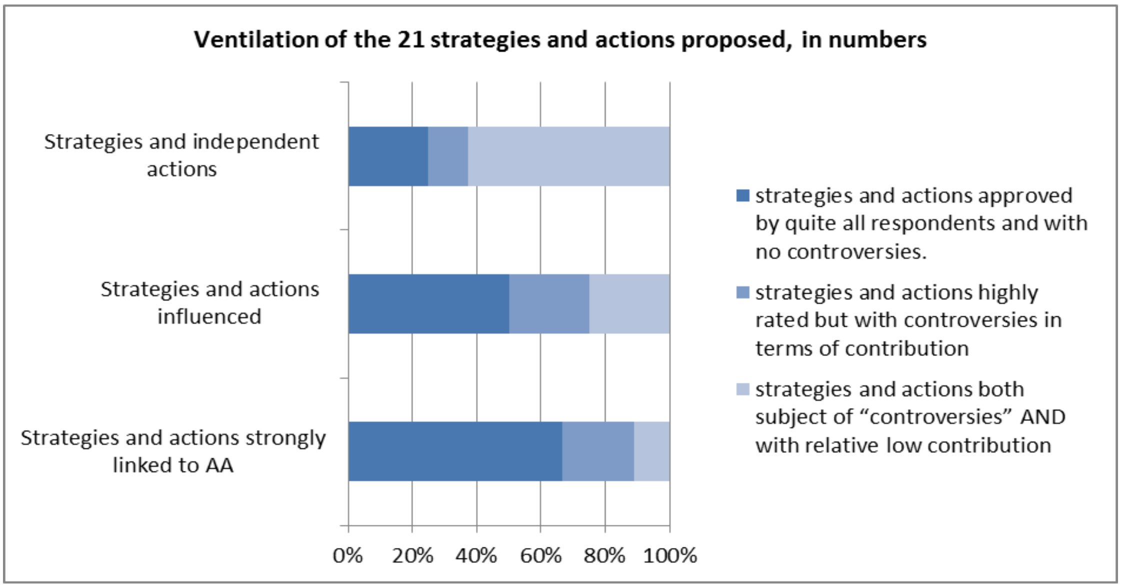


Fig. 3.
Analysis of stakeholders' answers according objectives

In order to explore more clearly those "controversies", a multiple correspondence factoral analysis has been conducted. Similarities were identified between the ratings and answers of

- Mobility managers in low demographic density (rural) territories and 75% of territories with a medium sized city with smaller satellites on one hand.

[3] Base : all answers

- Mobility managers in predominantly urban territories and 75% of polycentric network on the other hand.

Territories predominantly urban or with polycentric network are far more concerned about urban logistics, parking management and demand management than other territories.
Moreover, another characteristic of this second group is that 100% of "absolute necessity" ratings of "Improving links between harbours and their environment" are in this group.

4. Travelers behavior analysis

The objective of this analysis was to point out the feeling/ behavior of travelers living or going to low density areas or medium sized cities. The survey was conducted during the first semester of 2015 and concerned 3000 people over the AA (REPUTE 2015).

4.1. Sociotypes of travelers

Socio-types are built on three dimensions:

- The "size of modal habits" differentiates people who use only one mode of transport to those who use several (multimodality) . This mode is entered by frequency of use of different transport modes.
- The "values" dimension differentiates respondents describing the transport offer depending on individual interest (makes independent, comfortable, etc.) of those qualifying Transport modes according to the general interest (ecological, pollution, noise, etc.).
- The "size of the different attitudes" of the respondents according to their preferences of use, ie the opinion (positive, neutral or negative) they have regarding different transport modes.

Based on these dimensions, the typology was constructed with factor analysis of principal components which were used as variables for a Cluster analysis. The robustness of the groups thus created was then tested using topological log-linear models to ensure the identical structure of the building in different contexts (different types of cities and contexts of residence).
The groups are characterized by high homogeneity of actions underlying modal practices, particularly as regards:

- The differentiation between favorable adjectives to public transportation (rapid, practical, ecological, etc.) to those who are against (their expensive, slow, binding, etc.)
- the differentiation between adjectives relating to the cost of travel by public transport opposing "expensive" to "cheap"
- A strong differentiation between the ecological dimension of transport and polluting nature of private cars,
- A strong differentiation by use of transport modes.

To ensure reproducibility and comparability of the method, the complexity of the analysis in Key components used to construct the principles of this type, this one was simplified analytical method from the variables used in its construction. The typology obtained by this means has been optimized to be as close as possible socio-kind from the multivariate analysis. In the end, eight socio-types are selected.
The eight socio-type identified in this study are:

1. Convinced exclusive motorists only use the car in everyday life; their routes are structured around accessibility offered by this means of transport.
2. Opened exclusive motorists. The only difference with previous group is the positive attitude regarding public transport ; they are therefore open abstractly their use.
3. exclusive alternatists never use automobile; their routes and activities are structured around the accessibility offered by public transport, walking and cycling.
4. Ecologists civic prefer the use of Green vehicles to be consistent with their beliefs.
5. Time comparators use the fastest mode of transport; they know public transport as well as automotive advantages and constraints and choose case by case.
6. Motorists forced (to the use of public transport). They prefer to use the car, but forced by parking, traffic…. conditions to use other means of transportation for everyday destinations.
7. Predisposed Alternative prefer to use public transport, walking or cycling to the automobile for the characteristics of the mobility offered by these modes.
8. Vicinity anchored : they do not like to travel by means of transport motorized; they are (or would be) strongly anchored in the vicinity.

Socio-types allow also to distinguish people categories according to:

- Their modal patterns between single-mode using a single mode of transport and
- Multimodal who use several (even briefly)
- Their values regarding mobility as they apprehend modes of transport so group or individual;
- Attitudes to whether they represent the different modes of transport so positive, negative or neutral.

4.2. Main findings

The analysis of the answers of the 3000 interviewed people lead to the following global tables which summarise the main outcomes.
The results of this survey showed that if households are highly motorized, they also have the opportunity to use Public transport, and for the majority of them by bus networks whose frequency is daily. The demand analysis confirmed that households used occasionally (ie less than once per month) public transport, even if they mostly traveled in private cars. Predispositions for the use of alternative transport to the car are strong. Age and country residence vary the distribution of socio-eight kinds, unlike the type of inhabited area. So, younger people are more prone alternative to the automobile.

Table 1
Repartition of sociotype according type of territories

	Peri Urban	Inter mediate	Rural nearby city	Rural far from city
Convinced exclusive motorists	1%	1%	1%	1%
Opened exclusive motorists	12%	18%	21%	12%
exclusive alternatists	3%	3%	2%	2%
Constrained motorists	4%	3%	3%	3%
Opened alternatists	43%	39%	43%	48%
Time comparators	25%	28%	22%	22%
Civic ecologists	1%	2%	1%	1%
Vicinity anchored	7%	4%	6%	8%
No Answer	4%	2%	1%	3%

Table 2
Repartition of sociotype according countries

	France	Ireland	Portugal	Spain	UK
Convinced exclusive motorists	1%	1%	1%	1%	1%
Opened exclusive motorists	34%	12%	12%	11%	11%
exclusive alternatists	1%	3%	2%	2%	5%
Constrained motorists	3%	4%	3%	3%	3%
Opened alternatists	29%	51%	48%	35%	46%
Time comparators	23%	18%	27%	42%	18%
Civic ecologists	4%	0%	1%	1%	1%
Vicinity anchored	3%	9%	4%	3%	10%
No Answer	2%	2%	2%	2%	5%

The eight socio-kind vary by country residence with:

- A high proportion of "proprietary drivers open" in France in connection with a strong attachment to the automobile;
- A "predisposed to alternative" among the Irish in connection with a mean age more lower than in other countries;
- "comparator time" among the Spaniards looking to move with fashion more suited to their needs in terms of cost, comfort and journey times;
- "exclusive alternative" and "anchored in the vicinity" (10%) in the UK, which is explained by a lower motorization and mobility costs more.

This study helps to have a comparable measure between Atlantic Arc regions for the collection of transport modes and modal practices. The collected database in this study could be the subject of further analysis in particular regarding links with commuting

5. Conclusions

Although logistics impacts on mobility were not considered in the citizens survey, the comparison between the 2 approaches point out several outcomes among which the most obvious were :

- The majority of travelers are flexible and opened to various transport modes ; they tend to choose according pragmatic criteria (time, cost,…) rather than by conviction. Then the deployment of efficient public and/or collective transport may offer a valuable alternative to private transport resource. This is in line with the first strategies/actions for policy makers.

- This should also push local authorities to give more importance to actions leading to enhance mobility conditions and services adapted to areas contexts which were not among the prioritized strategies in figure 2
- Green vehicles and renewable energies are not so requested by travelers

These first results are the basis for a more detailed study on these specific areas in the AA which should be launched beginning of 2017 aiming at increasing the knowledge on the match between behavior/ expectation and possible actions for reducing carbon footprint.

References

CIVITAS 2016. Demonstration measures. Available from Internet: <http://civitas-initiative.eu>.
CLIM 2013. Emilio Fernández, Dominique Breuil &alt, "Local and regional actions for carbon footprint reduction", Climatlantic project, 2013. Available from internet: <www.climatlanticproject.eu>.
CLIM 2015. V Seel, D Breuil, "Climatlantic: mobility strategies to reduce carbon footprint in Atlantic Areas". In proceedings of International CODATU Conference, Istanbul, Turquey.
ESPON 2013. *ESPON European* Observation Network, Territorial Development and Cohesion. Available from Internet: <https://www.espon.eu/main/Menu_Projects/>.
MAE 2011. Metropolitan Areas in Europe, FRUS, BBSR-Online-Publikation Nr. 01/2011.
REPUTE 2015. Fnal report on Renewable Public Transport Enterprise. Available from Internet: <www.reputeproject.eu/>.
SUMP 2015. Eltis, The urban mobility observatory. Available from Internet: http://www.eltis.org/guidelines/sump-guidelines.

ELECTROMOBILITY IN RURAL AND PERI URBAN AREAS

Dominique Breuil[1], Mohamed Khafallah[2], Abdelilah Hassoune[3]
[1] *EIGSI, 17000, La Rochelle, France*
[2] *Laboratory Electricals Systems & Energy – LESE, Hassan II University ENSEM, Casablanca, Morocco*
[3] *EIGSICA, Casablanca, 20000, Morocco*

Abstract: The communication focuses on rural and peri urban deployment of electromobility, where, in many cases, public transport is unavailable. The aim of the communication is to point out how electromobility can satisfy some aspects of the specific demands and reinitiate new ways of living in these areas. There are some general transport features which affect these areas such as:

- People living in rural areas may travel up to 50% further than their city counterparts;
- Lack of integration of different modes of transport;
- Lack of real-time information.

The first part is dedicated to the identification of the specificities regarding mobility demand (passengers and goods) in those areas; it is based on several surveys among which a large survey conducted during an Interreg Project over Atlantic Areas citizens living in such areas (from Scotland to Portugal) Several factors influences the behaviour of people living in these areas like demography, distances to attractive places or fuel availability must be taken into account. This survey showed also clearly the relationships between the citizens and their transport modes. The second part deals with the various technical solutions which can be envisaged to deploy electro mobility, the necessary adaptations to the local context. The last part concerns the methodologies to implement electromobility in these specific areas, the barriers and drivers..

Keywords: electromobility, rural and peri urban areas, sustainable transport modes, policy making.

1. Introduction

In most of rural , peripheral and landlocked regions, minimum services are available with reasonable cost but accessibility to services (distance and time) is often longer and public transport are not as well developed than in urban areas and the possibility to choose amongst different alternatives is concentrated in highly populated urban areas. Then residents are more owned car dependent and supply of goods is more restricted.
The "EU White Paper on Transport " objectives (EUWPT 2016) for reducing CO_2 and other pollutions represent a difficult challenge for the concerned local authorities which do not have a range of policies and resources as large as in those located in denser areas.
Several studies and reports have pointed out the challenges facing rural areas regarding sustainable mobility; environment (climate, air quality, health), energy efficiency or even territory attractiveness are concerned but the most important concern social ones which influences economic dynamic (job and services access, travel time, …)
Electric mobility is expected to play a major role for achieving these goals for three reasons: (a) The electric power train is significantly more energy efficient than the conventional one, (b) electricity can make use of energy from renewable sources available for transport, and (c) of connected to the power grid, batteries of electric vehicles could stabilize the grid and balance supply and demand and thus facilitate the integration of renewable sources.
Moreover, Electromobility is a vector for changing mobility behaviour and new services will facilitate these evolutions especially in these territories.
Therefore electro mobility should be more developed in rural areas but solutions must be adapted to the local context. Demonstrations have been launched (cf for instance European Alternative Fuels Observatory reports) providing a better knowledge on the adaptations to be realised, on the drivers and barriers specific to these situations.

2. Mobility in rural areas

Rural communities can include a number of complex and contradictory specificities However, it is possible to identity some common criteria which have significant direct or indirect influence on the organisation and deployment of mobility solutions, mainly their nature, demography and localisation as well as the transport demand (residents' expectations).

2.1. Nature

Most rural communities can be grouped into five categories (ICMA 2010) though many may fall into more than one:

- Gateway communities are adjacent to high-amenity recreational areas such as National Parks, National Forests, and coastlines. They provide food, lodging, and associated services mainly linked to tourism
- Resource-dependent communities are often home to single industries, such as farming or mining, so their fortunes depend on an external market
- Edge communities are located at the fringe of metropolitan areas and typically connected to them by state and interstate highways. They provide their residents with access to economic opportunities, jobs, and services…

[2] Corresponding author: dominique.breuil@eigsi.fr

But precisely because they are such attractive places to settle, edge communities often face pressure to continue to provide more housing and services to new residents.

- Traditional Main Street communities enjoy compact street design that is often accessible to a transportation hub. Still, these communities often struggle to compete for tenants and customers with office parks, regional malls, and big box stores.
- Second home and retirement communities may overlap with some of the above groups, particularly edge communities and traditional Main Street communities. They often struggle to keep pace with new growth while maintaining the quality of life that drew in residents in the first place.

2.2. Demography and social issues

The key social process in contemporary rural change is migration which depends on three factors (EDORA 2013) :

- the “rural exodus” which (selectively) drains human capital out of remote rural areas, in favour of urban and accessible rural locations;
  the flow of economic migrants from the poorer regions of the New Member States (NMS12) towards both rural and urban regions of the EU;
- “counter-urbanisation” movements from cities and towns into accessible rural areas.

The social and economic impacts of the first of these upon the origin regions are predominantly negative. The other two kinds of flow result in a complex balance of positive and negative effects upon rural regions.
These three types of migration bring new population in the areas and lead to a changes in demand and behaviour regarding mobility independently of the (more or less according to areas) demographic ageing. These changes are linked to the requirement for a certain level of quality of life and access to services (education, health, social services, NTIC ….)
These structural changes in the rural economy is associated with changes in the robustness and capacity of local communities and lead to new ways of rural governance, including the organisation of mobility and the appetence for new technologies such as electromobility. For instance, the report on metropolitan areas in Europe (MAE 2011) proposes 6 types of residents' attractiveness which must be fulfilled by local authorities (and of course accessible):

- Living facilities : housing, shops, crafts,…
- Social facilities : transport, health,…
- Administration : politics, law & courts, police…..
- Innovation & prospective : research, education, innovation,…
- Culture : arts, sports, tourism
- Economy : industries, services,…

2.3. Accessibility

Accessibility is a two dimensions driven variable: Accessibility consists of two components, available activities of interest and transport infrastructure leading to them. Accessibility is important because it provides access to opportunities at distant locations or makes it possible to receive goods and services or visitors from distant locations. For policy making, the maximisation of accessibility is therefore an objective only as far as it helps to improve the quality of life by facilitating access to opportunities, goods and services and so participation in social and cultural life (TRACC 2015).
Several surveys (like SURVEY 2008, SURVEY 2011, SURVEY 2015), point out the main characteristics of sparsely populated areas (as shown in fig 1 and 2 below):

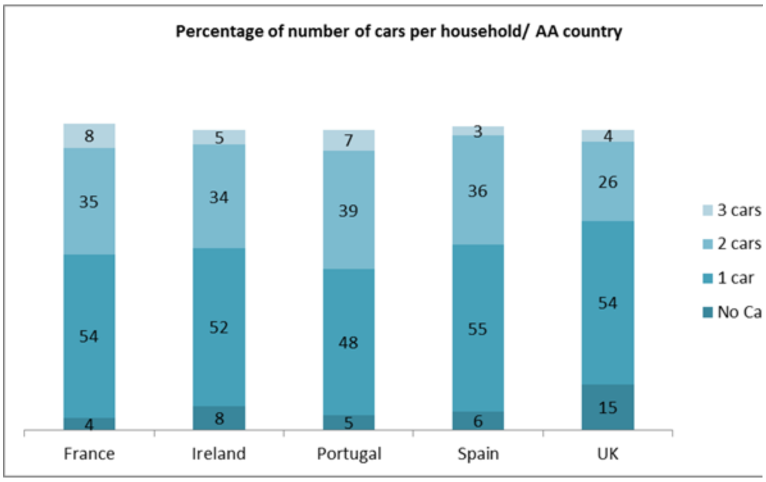


Fig. 1.
Percentage of number of cars per household / AA country

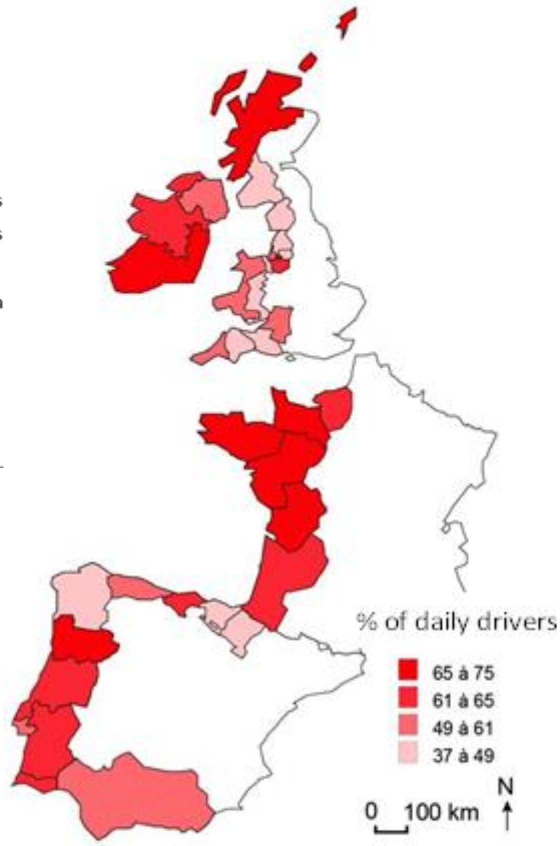


Fig. 2.
Percentage of daily drivers

- Daily trips longer in distance, not really in time ; the average length for home to work trips is 21 to 25 kms and average time 20 to 30 mns, but there are significant differences according to the countries, average 24kms in Ireland and UK versus 13 kms in France, Portugal and Spain
- 75% of trips are realised by cars, due to very poor public transport networks more oriented towards school travels for children than other categories of travellers
- A high number of short travels, globally half of the travels are less than 5kms and realised quite quickly
- Very small practices of intermodality (use of several transport modes in the same trip)

However, no significant differences have been observed by the TRACC project (TRACC 2015) for performance in regional and local accessibility between regions located at the European Periphery and regions located at the European Core. Regional case studies have revealed relatively homogeneous patterns within regions ; this was also observed on the Atlantic Area regions (SURVEY 2015, cf below)

2.4. Targets and demand

The knowledge of residents' behaviour regarding mobility is somehow biased by the availability of transport modes. Although globally, mobility drivers are the same as those of people living in densely populated areas, some expectations and practices regarding transport modes and resources are different due to the way of life in the various types of rural communities. These differences concern mainly:

- The number of cars per household depends on the remoteness, for instance 45% of households in rural areas have more than 1 car instead of 30% in urban areas (SURVEY 2015 / not counting cities over 100 000 inhabitants)
- Seniors mobility decreases with ageing, from more than 3 travels/day before age of 75 to 1.5 travels/day between 75 and 85. The motivations of seniors for travelling are : Health 59%, Family 51%, Travels 41%, Leisure (sport, association, shopping…) 41%, Reading 32%(survey Panel Progrès October 2015)
- Adults, working or not residents tend to work in their area, for instance 90% of people leaving in rural areas (like Traditional Main Street) work in the same area (SURVEY 2015). 77% of them drive their cars daily to go to work.
- Young people represent a very specific demand category since they usually do not own a car and few of them use a 2 wheels vehicle for a school or leisure purpose. Students (eg older ones) strongly use public transport (for instance 37% of daily trips in SURVEY 2015) . Young people mobility in rural area is a critical problem

which retain some family to live in those territories since all activities other than school are rarely accessible through public transport ; then parents have to drive their children to the concerned places.

- Tourists represent also a growing demand (INTEGRA 2013, ATOUT 2014); in general the more remote an area is, the more interesting it is for tourists ! Their demand regarding mobility presents several aspects from very short distances inside a city, larger ones around the country side or to travel from one area to another.
- Goods delivery and transportation have also their own specificities. The transport problems are inversed since usually travel time to go through a village or a small city is quite short although the distances between delivery points are longer than in urban areas. New behaviours are emerging with the growth of e commerce whether goods are home delivered or collected by receivers in specific points ; these modify the organisation of runs by logistics operators and/or is a source of new trips for inhabitants.
- Farmers and all the local food transformation activities represent also a specific demand. Agricultural machines (especially tractors) are mainly fuelled with oil and represent the 53% of the energy consumption for agriculture with2.090 ktep per year ; other consumers are breeding buildings and greenhouses 430 ktep (11 %) et 400 ktep (10 %). (TERRE 2014).
- Handicapped people who have the same demand that previous ones but require specific adaptations in the infrastructure and vehicles as well as accompanying persons

3. Possible Electromobility solutions

Development of electromobility in rural and peri urban areas may be considered according to four axes, like in all areas, but with some specificities

- The technologies : infrastructure and vehicles
- The services directly or indirectly linked to the deployment of electromobility and related organisation
- Finance since deployment of electromobility requires several investment sources
- Regulations

3.1. Technology axes

Infrastructures

In many EU countries, policies for deploying charging stations network have been designed and implemented. However, they concern mainly cities and main transport corridors. During the recent years, charging stations have also been installed in some quite small cities (less than 10 000 inhabitants, cf the European Alternative Fuel Observatory statistics in EAFO 2016). Unfortunately, many of these implementations have been done from a politic point of view and are not as successful as expected for pragmatic reasons (independently of the scarcity of vehicles) :

- The large majority were "slow" charging stations (4kw)
- They were installed according a marketing / political approach, often in wrong places regarding flows and efficiency; for instance charging at rail stations : if someone plugs its car during its journey, the station is unavailable during all this time…..

An important difficulty in rural situation is the grid connection. If a fast charging station (>40kw) is to be installed in the country side, the connection to the grid might be not powerful enough to support such power requirement. Hopefully the new fast charging stations, equipped with a buffering battery may decrease the instantaneous demand.
Moreover, the majority of population in those areas live in their own houses, contrarily to urban one which facilitates home charging and consequently decreases the need of on-street or parking stations and modify (in the right way) the ratio stations/ household.

Vehicles

Considering the demand, the variety of vehicles to satisfy mobility requirements inside those areas can be grouped in 4 categories :

- Vehicles able to go to the nearest town, for daily work trip or less frequent moves (like shopping, leisure…) ; the average return distance is less than 100kms, which is less than the autonomous range of current EVs (Electric vehicles). Owners can be also reassured if (rapid charging 20Kw) stations are available at their work or in the town
- Vehicles to go around the area, light vehicles or 2 wheels which can easily satisfy moves inside small cities, between villages…
- Professional vehicles for craftsmen, famers, local logistic operators ; today several electric vans or small trucks are available on the market with reasonable performances. In a few years, larger ones will be ready at reasonable costs, some of them been currently manufactured (for instance 19t truck developed by Emoss…) with a satisfactory battery autonomy range. Electric tractors are not yet enough performant but several prototypes exist and it is expected to have some cost reasonable ones on the market before 2020. One important aspect of these machines is their ability for autonomous or remote controlled driving ; this is much easier to realise than autonomous vehicles in city and may grandly facilitate farming (cf for instance the

Autonomous Tractor Corp. of Fargo) as many other electric machines (cf drones to monitor and analyse plants growth.

- Collective transport for which there is already a large panel of e-buses ranging from 12 seats to double-deckers in London on the market. Various en route charging solutions to increase the distance are demonstrated in several cities to reach distant suburbs which could be easily transferred in country side (cf ZeEUS)

3.2. Services

Several mobility services may be adapted to fulfil transport demand with EVs. This adaptation is linked to the context and to the necessity to reach an equilibrated financial balance (eg specific Business models). Some of them have already been implemented and brought out valuable outcomes such as the following.

- Experimentation of EV car sharing have been deployed and lessons learned from these various implementations, for instance the car pooling experience in Poitou Charentes called REGIONLIB (ended in 2016). One major difficulty is the localisation of the car stations : if the customer must take his car to reach the station, then he will continue his trip and it is impossible to ensure the availability of cars in all villages. Then there are several solutions, one is the reservation of a car which was never really successful, another one is the reservation of a car and a chauffeur which completely changes the business model and provides a secure travel for all elderly people living in the country side or youngers going to extra scholar activities…. and creates employment.
- The utilisation of public fleet by authorised drivers ; since EVs or E buses are expensive, the local authorities which buy them may rent these vehicles when not used by the public staff to other institutions like retirement mansions for excursions, local associations, local very small enterprises.
- E bikes or scooters for tourists which may travel from one area to another if local authorities cooperates, sometimes through tourism offices ; this is also feasible with e boats on canals or rivers.
- Rural Consolidation Centres (with E Vans) which may avoid logistic operators to spend time and money on isolated delivery trips. As for the Urban CCs, they must provide several services (not only cross docking and delivery) to be profitable like temporary or dedicated storage (ex for craftsmen), last end supply chain activities…

3.3. Finance

Local authorities of these areas do not have the same resources and finances than larger communities. Therefore they need to find other funding sources for their investments, the deployment of infrastructure or promotion of cleaner transport modes. Apart from subventions given by various institutional bodies or bank loan three possibilities are often used:

- Grouped procurement by several local authorities, which makes for instance charging infrastructure more affordable and coherent over a larger territory
- Collaborative funding with individuals or local bodies which has been already used for vehicle sharing stations and vehicles and is quite appropriate for small areas
- Other private partnership with enterprises liked for instance the management of Consolidation centers

Moreover they cannot use some incentives offered to urban citizens like free car park for EVs, dedicated lanes or specific delivery areas. But specific ones may be developed like the access to "good" market places for sellers' market, priority for some administrative services,….

3.4. Regulation

As in larger cities, deployment of electro mobility must be accompanied by the strict application of regulations intending to favour electromobility. Small cities or communes may create access controlled zones in inner town, prioritise EV parking or access in historic, touristic places (ex country roads, wood trails,…)

4. Implementation, drivers and barriers

Many European local and regional authorities have put in place e-mobility measures but not so many have developed e-mobility policies and included them in the overall mobility strategies. On another hand, specificities of electro mobility are not clearly taken into account in the proposed methodologies to deploy clean, sustainable mobility plans in rural or peri urban contexts, cf for instance Polycentric SUMPs (PSUMP 2015) or Metric tools (JRC 2015), the "plan de mobilité rurale" (CEREMA 2016). EU projects like ZeEUS (ZeEUS 2016) or FREVUE (FREVUE 2016) are mainly focused on larger cities demonstrations and resulting guidelines are more appropriate to urban implementations than rural ones.

Some European projects have experienced how to develop e-mobility strategies in low demography areas, such as for instance the ELMOS (ELMOS 2016) and REPUTE (REPUTE 2015)projects providing valuable context related lessons and information which are first outline to the definition of E-mobility strategies in rural areas.
The global implementation approach remains valid and is similar for all electro mobility projects, especially the necessity to set up a holistic approach encompassing all stakeholders' expectations (passengers, logistics operators, professional..) and integrated in overall land planning strategy. However some aspects must be considered with specific concern, mainly the following.

- The scarcity of reliable data concerning traffic flows, local practices etc. ; such situation often requires a detailed diagnosis at the beginning which takes time in order to obtain a representative cartography of the flows, a comprehensive vision of behaviours, practices and expectations.
- Linked to above, the definition of specific indicators to measure the progress
- The step by step deployment of electro mobility measures along with other clean mobility actions ; this deployment must be planned according to the envisaged technical evolutions as well other constraints like finance, citizens changes and awareness…
- The necessity to develop new governance schemes, often coordinated between several territories and involving public/private partnerships like for instance vehicle sharing managed by tourism offices or social institution for old and/or disabled people

Barriers and drivers in rural context are also similar to those in urban one with few differences ; main barriers are still :

- Costs since vehicles are still more expensive than oil fuelled ones, even with national or regional subventions
- Perceived autonomy which will become less a barrier with the evolutions of the batteries (currently 250kms) and the deployment of networks for long distance travels
- The lack of specialised vehicles, especially for professional utilisation or adapted to country trips which should be filled in a near future (before 2025)

Concerning drivers, main ones are

- Examples given by local authorities, local politicians , public bodies owning EVs in their fleet
- Information addressing specifically all targets, promoting electro mobility as well as proposing new vision of multimodality and intermodality.
- The deployment of new services managed by centralised institutions over one or several territories for specific targets especially concerning collaborative mobility or sharing vehicles

5. Conclusions

Mobility is a key stone to keep alive rural and peri urban territories which can be further developed if services are accessible as in larger cities. New information technologies (NTIC) may facilitate working in these areas but people living there will still need to travel easily from these places even if the travel behaviours regarding modality will change with the next generations.
Electromobility is just at the beginning, progress in the range autonomy are expected in the next future for all modes and development of charging facilities will also be facilitated by these evolutions. Combined with NTIC it will support the sustainable revitalisation of many territories providing a good quality of life of residents and offering nice hosting and travel conditions to tourists and visitors. The recent developments done for autonomous vehicles in real life situation like in La Rochelle (CITYMOBIL 2016) or the experiences of Rambouillet city show the way for the mobility in low demography territories.
However new business models have to be set up based on collaborative approach between residents, local authorities and enterprises in order to optimise the multi modality which satisfy the demands of the various categories of inhabitants; In the same way, new mobility behaviours have to be generated among the population leading to a larger use of multimodality facilities.

References

ATOUT France, 2014. "The “Contrat de Destination”, a tool for Territories. In proceedings of *2nd Forum on Interegional Mobility*, EIGSI, La Rochelle.
CEREMA, 2016. Le plan de mobilité rurale (Rural SUMP), Collection références.
CITYMOBIL, 2016. Evaluation report. Available from Internet: <http://www.citymobil2.eu>.
EAFO, 2016. Electric vehicle charging infrastructure. Available from Internet: <http://www.eafo.eu/>.
EDORA, 2013. European Development Opportunities in Rural Areas. Available from Internet: <https://www.espon.eu/main/ Menu_Projects/Menu_ESPON2013Projects/Menu_AppliedResearch/ edora.html>.
ELMOS, 2016. Introducing electric mobility as intermodal transport mean in small and medium sized cities in the South Baltic Area. Available from Internet: <www.elmos-project.eu>.
EM GUIDE, 2015. “The future of the automotive industry in our territories”, Electromobility Guide for Local and Regional Authorities, Intergroup, Committee of the Regions, European Commission.

EUWPT, 2016. Roadmap to a Single European Transport Area, the implementation of the 2011 White Paper on Transport, European, Commission staff working document.
FREVUE 2016, Demonstrator progress review, Freight Electric Vehiclesin Urban Europe project. Available from Internet: <http://frevue.eu/>.
ICMA, 2010. "Putting Smart Growth to Work in Rural Communities", ICMA report.
INTEGRA, 2013. "Motivation of interregional travellers in Atlantic Area" , START project. Available from Internet: <www.start-project.eu>.
JRC, 2015. Smart guide on regional transport innovation strategy, JRC technical report.
MAE, 2011. Metropolitan Areas in Europe, FRUS, BBSR-Online-Publikation Nr. 01/2011.
ORTPC, 2014. Bonnes pratiques de Mobilité en Poitou Charentes, Observatoire Régional des Transports en Poitou Charente. Available from internet: <http://www.ort-poitou-charentes.asso.fr/category/etudes/>.
PSUMP, 2015. The Poly-SUMP Methodology, guidelines. Available from Internet: <http://www.poly-sump.eu/home/>.
REPUTE, 2015. Fnal report on Renewable Public Transport Enterprise. Available from Internet: <www.reputeproject.eu/>.
SURVEY, 2008. Enquete nationale transports et déplacements, (French national survey on households travels), CEREMA, France.
SURVEY, 2011. Enquete déplacements au Pays de Puisaye Forterre, CEREMA 2011.
SURVEY, 2015. "Mobilité Espace Atlantique Hors Grande Ville" Rapport final 2015, EIGSI / 6T,REPUTE project. Available from Internet: <www.reputeproject.eu/>.
TERRE, 2014. L'efficacité énergétique des exploitations (eenergy efficiency in agriculture) Terre-net. Available from Internet: <http://www.terre-net.fr/actualite-agricole/economie-social/article/l-efficacite-energetique-des-exploitations-a-augmente-de-40-en-40-ans-202-100880.html>.
TRACC, 2015. TRansport ACCessibility at regional/local scale and patterns in Europe, Final Report - Executive Summary and Main Report. Available from Internet: <https://www.espon.eu/main/Menu_Projects/Menu_ESPON2013Projects/Menu_AppliedResearch/tracc.html>.
ZeEUS, 2016. ZeEUS Newsletters 1 to 6, ZeEUS publications. Available from Internet: <http://zeeus.eu/>.

ESTIMATING THE HOURLY VARIABILITY OF BICYCLE TRIP PATERNS AND CHARACTERISTISC FROM AUTOMATIC BICYCLE COUNTERS: CASE STUDY IN PRAGUE, CZECH REPUBLIC

Vojtěch Jirsa[1], Yusak O. Susilo[2]

[1] *University of Pardubice, Jan Perner Transport Faculty, Department of Transport Technology and Control, Czech Republic*

[2] *KTH Royal Institute of Technology, Division of System Analysis and Economy, University in Stockholm, Sweden*

Abstract: Nowadays it is common for many cities around the world to use automatic bicycle counters laid at main road segments to monitor the cyclists' traffic flow at any given time in the given location. In most cases, this data is then used to identify the peak period of the bicycle traffic. This paper introduces a method to classify the characteristics of bicycle traffic flows and inferring different proportion trip purposes based on the variations of hourly counts. Whilst of many previous studies investigated the key determinants of bicycle travel demand detected by these counters, none of these studies tried to distinguish different portions of different traffic characteristics in each counting section. In most cases the trip purposes of cycling were grouped into either prevailing utilitarian or prevailing recreational. In reality, however, these recorded bicycle traffic contains both trip purposes. The method which is introduced in this paper was developed and tested on the longitudinal datasets obtained from the bicycle counting system in the city of Prague over five years' period, i.e. 2010 to 2015. The system consists of 26 counting facilities in various city quarters covering wide variety of road segments. In achieving the study objective, first, a theoretical assumption was done to differentiate three different basic traffic characteristics and their respective hourly variations, i.e.: utilitarian, recreational affected by workhours, and recreational not affected by workhours. These hypothetical hourly variations were tested and confirmed based on the observed Prague sample. Obtained results were discussed with respect to geographical location, built environment and knowledge of local situation. The hourly variations of the recorded bicycle flow were influenced by the build environment factors such as specific land use in the proximity of counting section. The results also indicate some specific routes (and its direction) preferences.

Keywords: cycling, traffic characteristics, hourly variations, optimization.

1. Introduction

Many studies have been carried out measuring impacts of various factors on the use of bicycle and some of them more specifically measuring the impact on bicycle traffic flows (e.g. Thomas et. al., 2012; Miranda-Moreno and Nosal, 2011; Cools, 2009). Different characteristics of bicycle traffic such as utilitarian or leisure showed different sensitivity to explanatory variables such as season, built environment, weather, etc. Among others Liu et. al. (2014, 2015) proved in his mode choice oriented studies that the impact of weather is more significant for leisure cycling than utilitarian. This was also confirmed by studies devoted solely to recreational cycling (e.g. Hamilton, 2005; Jeuring and Becken, 2013).

None of the analyses, focused on bicycle traffic flows, included the characteristics of bicycle traffic flow as continuous explanatory variable. This is due to the fact that information about the trip purpose for every single count is not available. Some of the authors of previous studies made the presumptions about the prevailing traffic characteristics in particular sections according to the knowledge of the local situation. Thomas et. al. (2012) distinguished three types of cycling paths: utilitarian, recreational and mixed according to their location in built environment (connecting municipalities, open to the country side, mixed). Brandenburg at al. (2006) divided counts in two categories according to the time of counting: commuting (working-days between 0700 and 0900 CET) and recreational (working-days after 0900 CET and weekends). The later division is questionable since it presumes that no cyclists commute from work in the afternoon. Other studies performed the analysis for each counting section separately (Miranda-Moreno and Nosal, 2011) and obtained different model parameters for each section.

In modelling dependency of cycling flows on various factors the more comprehensive consideration of bicycle traffic characteristics is necessary. Knowledge of bicycle traffic characteristics is important not only for assessment of the significance of various influencing factors (and hence evaluation of trends and prediction). In practice traffic planners may be more interested in utilitarian cycling which has the potential to relieve other transport modes, while health professionals and tourism workers may be as well interested in leisure trips. This paper suggests the possible classification of bicycle traffic characteristics and outlines the method for calculation of different traffic characteristics ratio for particular section. The calculation is based on hourly variations of traffic flows during working-days and the method used is linear optimization.

In following chapters, first the data sample will be introduced. The time-bound variations analyses will be followed by the theoretical assumptions about the different characteristics of bicycle traffic. Then the used method for bicycle characteristics assessment and calculated results will be described and discussed.

[1] Corresponding author: Vojtěch Jirsa: vojtech.jirsa@upce.cz

2. Data explanatory analyses

2.1. Study area description

The data used in this study was collected at Prague, the capital of the Czech Republic. The area of the city is 496 square kilometres with roughly 1.3 million inhabitants. It has a good public transport system which covers 43 % of all trips, share of pedestrian trips is 23 % and car trips count for 33 % (TSK, 2014). According to the annual report of city authority responsible for the development and maintenance of road infrastructure (TSK) (TSK, 1988-2014), Prague has rather small mode share of cycling – 1 % of all trips. This figure is monitored from 2007 and remains unchanged until 2014. Over the last years, cyclists are continuously counted in several locations. Whilst in some locations there were not substantial changes captured in bike counts, in some other locations, there were found multiple increases in term of bike counts. This increase was not a surprise as the cycling infrastructure in Prague has been steadily improved over the last few years.

2.2. Data collection and sample characterization

The data used in this study were collected with the system of automatic bicycle counters. The technology of counters is based on processing of electric current induced in the wire loop installed under the pavement. Counters can distinguish bicycles from cars, busses, strollers and other road and sidewalk users and can be used at various types of cycling infrastructure both on and off-road.

In 2015 there was 26 counters installed at different locations. First seven counters were placed in 2010. In 2011 there were altogether 20 facilities with installed counters. The data available from most of the counters were collected during the years 2011 and 2015. In each section the missing and inadequate values were recorded in periods of temporary facility closures and minor counter malfunctions. The data set was thoroughly analysed to remove missing and inadequate values (through the analyses of aggregated daily counts). The data were logged in one hour intervals separately in both directions. The map in figure 5 shows the intention to distribute the counters at the locations with high demand of cyclists such as road arterials, locations along rivers and other natural and artificial barriers and places where the barriers can be overcome. Counters are placed on both on-road bicycle infrastructure (usually bike lanes) and non-motorized paths (usually mixed cycling and pedestrian paths). Either locations with expected leisure and utilitarian cycling are included. The data are collected by TSK and available from the website (Camea, 2015).

Figure 1 comprises the overall information about the sample size and its quality. The height of the columns represents the overall time of operation for each counter from January 2010 to December 2015. Seven counters were in operation over 70 months. The total time of missing values and identified malfunctions is marked in blue and green respectively. The time of one-direction counting is marked in orange and valid both-direction counts in grey. The counters are designed to count in both directions. Therefor the unidirectional counting is considered an error and for further analyses all one-direction, missing and malfunction values were excluded from the sample. Yellow curve in the graph shows the total valid counts in each location. The highest record was captured in the location "Modřany" with over 2 million counts.

Three counting facilities were excluded from the sample (the error records accounted for over three quarters of overall entries): Hlubočepská, Košíře, Podolské nábřeží – vozovka. No valid counts are available for facility Košíře at all. Data available for facilities Hlubočepská and Podolské nábřeží - vozovka are few (less than one-year time period) and do not cover all seasons, which would compromise the accuracy of results.

2.3. Hourly Variations of Bicycle Traffic Flows

As can be seen from Figure 2 and 3, there were a clear pattern of hourly variations among observed working-days and non-working-days, respectively. In this study analysis, the dataset was divided into two groups: a) working-days (excluded weekends, bank holidays and national school holidays); b) non-working-days (weekends and bank holidays). Average hourly variations for the whole operating duration were calculated for each counter. Then average shares of daily counts were calculated for the better interpretation and comparison (see Figure 2 for non-working days and Figure 3 for working-days).

Two typical hourly variations may be identified for non-working-days. Both types are characterized by rising intensities in the morning hours. For the first type the growth slows down around 10am to 11am but continues growing until the intensities start to decrease approximately between 5pm and 6pm. The second type is characterized by slight drop during the lunch hours (11am to 1pm) and by ongoing growth until approximately 3pm to 4pm, when the intensities start to decline. For the second type the growth and decline is steeper than for the first type. Nevertheless, the difference between both types is insignificant. The drop during the lunch hours, which is characteristic for the second type, is always less than 2 % of share of daily intensities. These minor differences may be caused by different ratio of utilitarian/recreational trips, but also by another hidden trip characteristic (proximity of significant employer with weekend shifts, etc.).

For working-days the differences between typical hourly variations patterns are more significant. Three basic types may be identified. The first type is characterized by significant morning peak between 7am and 9am, followed by significant drop (e.g. drop over 7 % of share of daily intensities) with the minimal intensity around noon and evening peak between

5pm and 7pm. The morning peak is roughly equivalent to the evening peak. It is presumed that the first type represents sections with prevailing **utilitarian** cycling (cyclist going to work in the morning and back home in the evening). This first type of variations (utilitarian) was recorded in 16 of 23 counting facilities.

Second type of variation in working-days is characterized by gradual increase in morning and forenoon hours with accelerated growth in the afternoon and peak between 4pm and 6pm. It can be assumed that this type of variation refers to **recreational cycling which is affected by working-hours**. Distinctly higher intensities in the afternoon hours may be due to cyclist going for a ride after they have returned from work (e.g. afternoon peak is 10 % of share of daily intensities higher than morning hours).

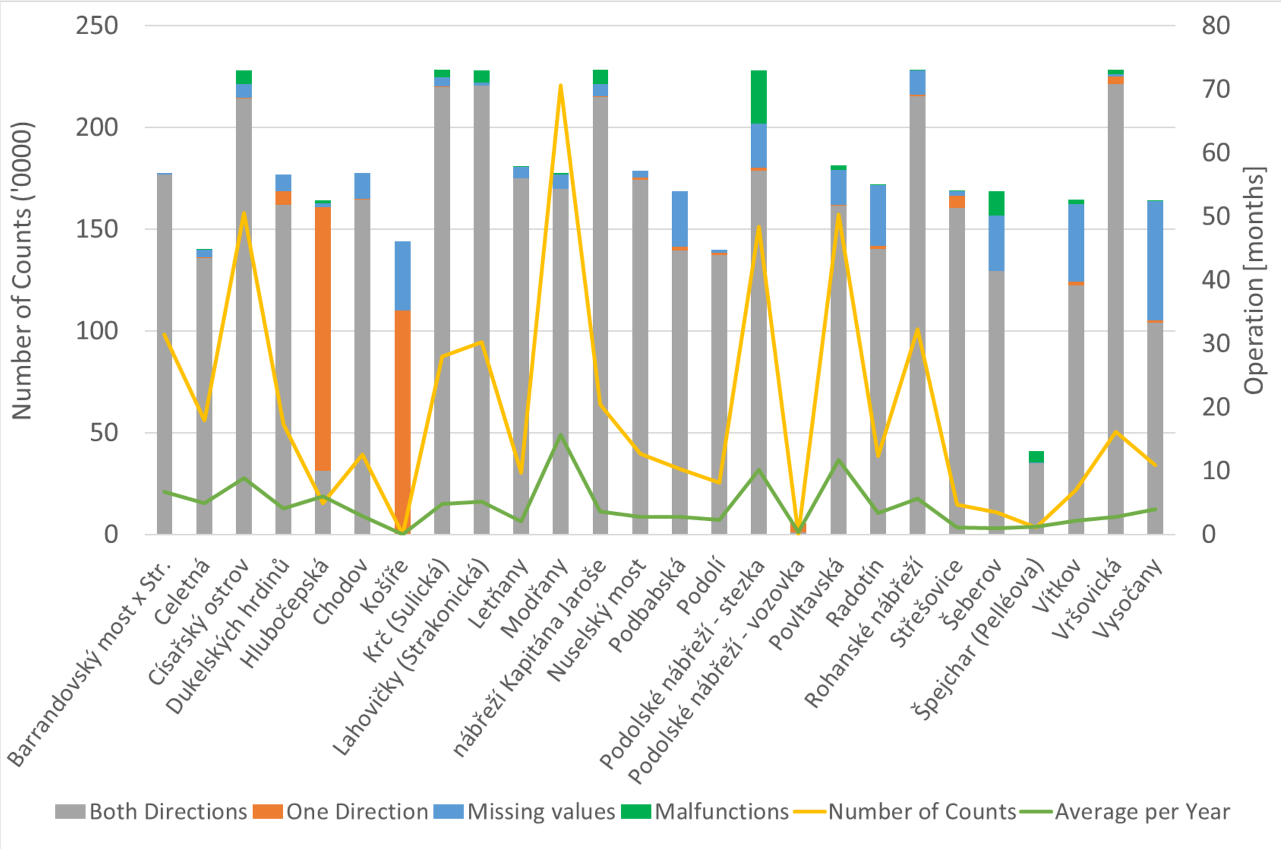


Fig. 1.
Sample size and quality

Last type of variation in workday was recorded by only one facility. This type of variation is remarkably similar to the variations in non-working-days. It can be presumed that this type of variation is characteristic **recreational cycling not affected by working-hours**. After the morning growth the intensities remain constant until 7pm when they drop.

In most of the sections the recreational (either affected or not affected by work hours) and utilitarian trips are mixed in different rations. In the figure 4 three examples of herein described typical variations are depicted. These variations were selected as they the best characterize three described type of basic variations. While estimating the ration of different traffic characteristic in each profile (see chapter 3) variation in the figure 4 will be taken as a reference.

3. Estimating the Traffic Characteristics

3.1. Assumption for the hourly variations

The estimation is based on the hourly bicycle traffic variations during working-days, since the differences in working-days variations are more distinctive than differences in non-working-days variations. Hypothetically there are three basic categories of hourly bicycle traffic variations:

a) utilitarian (U)
b) recreational affected by work hours (RA)
c) recreational not affected by work hours (RU)

Presumably in most locations all three categories contribute to the overall traffic flow. In the following section the method of calculation of the share of different traffic characteristics on overall flow in individual location is described.

3.2. Calculations

For each location it is assumed, that traffic counts for certain time period (I_T) may be calculated as sum of contributions of all cycling traffic characteristics in respective time period. In equation 1 these contributions are represented by I_{TU}, I_{TRA} and I_{TRU} (utilitarian, recreational affected and not affected by work hours respectively). The same relationship

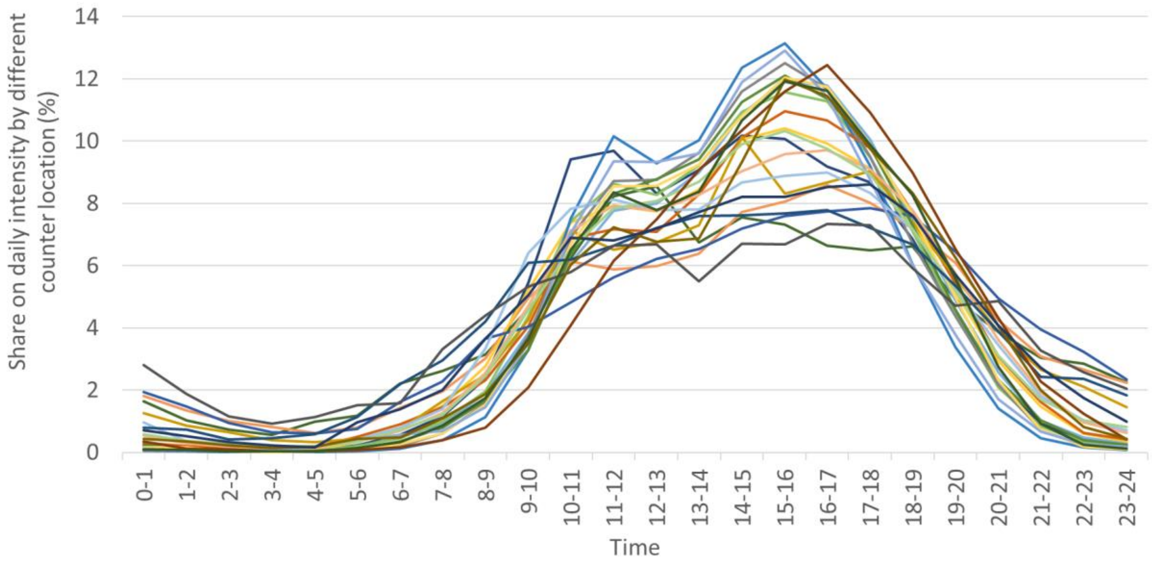


Fig. 2.
Average shares of daily counts – Non-working-days

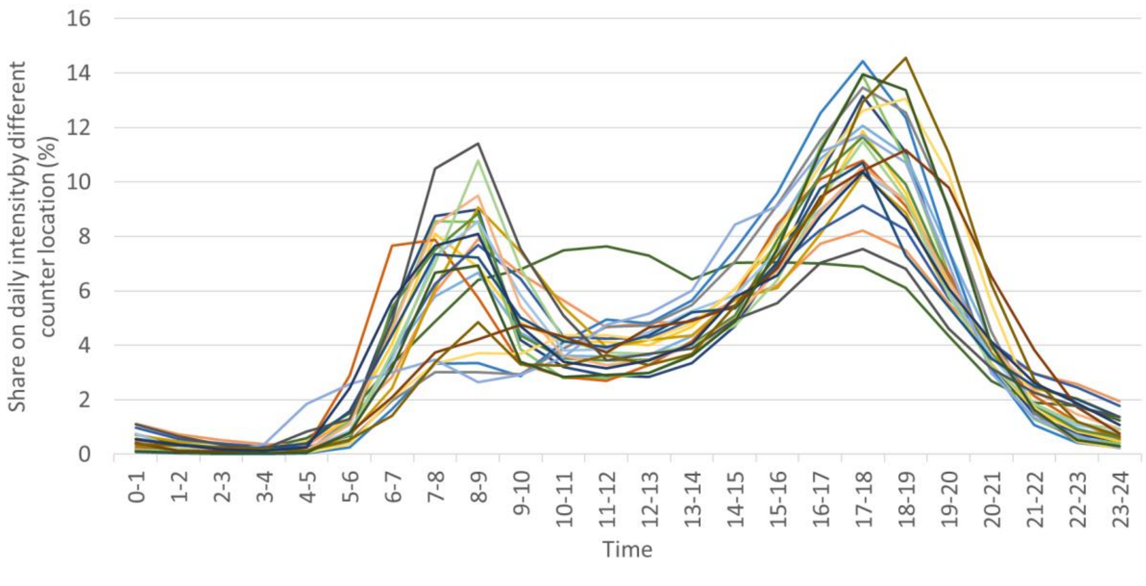


Fig. 3.
Average shares of daily counts – working-days

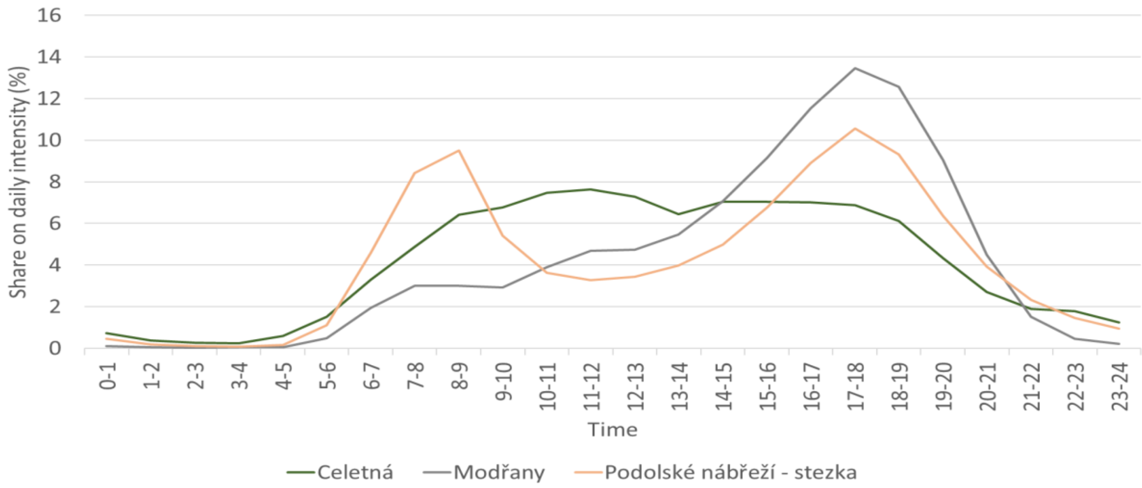


Fig. 4.
Average shares of daily counts – working-days, reference sections

can be written for shares on daily counts for certain time period (see equation 2).

$$I_T = I_{TU} + I_{TRA} + I_{TRU}. \tag{1}$$

$$\frac{I_T}{I_{24}} = \frac{I_{TU}}{I_{24U}} + \frac{I_{TRA}}{I_{24RA}} + \frac{I_{TRU}}{I_{24RU}}. \tag{2}$$

Similarly, the shares on daily counts can be calculated for hypothetical one-trip purpose locations. These can be referred as reference shares R_{TU}, R_{TRA}, R_{TRU} (see equation 3). In this case study, reference locations were approximated by selecting locations with the highest level of conformity with anticipated daily variations and according to the knowledge of local situation. To calculate reference shares, variations from figure 4 were taken into account.

$$R_{TU}=\frac{I_{TU}^{r}}{I_{24U}^{r}},\ R_{TRA}=\ ,\ R_{TRU}=\frac{I_{TRU}^{r}}{I_{24RU}^{r}}. \tag{3}$$

In equation 4, variables P_U, P_{RA}, P_{RU} represent the share of individual trip purposes on overall counts. The contribution of each traffic characteristic to the share on daily counts for certain period is the product of respective reference share and P_U, P_{RA}, P_{RU}. Expression 2 can be adjusted as:

$$\frac{I_T}{I_{24}} = P_U \cdot R_{TU} + P_{RA} \cdot R_{TRA} + P_{RU} \cdot R_{TRU}. \tag{4}$$

Next, the values P_U, P_{RA}, P_{RU} are optimized, so that the total difference between the two sides of equation 4 for various time periods is minimized. Optimization is done with the linear programming (gradient method) and the problem is defined as follows:

Minimize:

$$\left|\frac{I_T}{I_{24}} - P_U \cdot R_{TU} + P_{RA} \cdot R_{TRA} + P_{RU} \cdot R_{TRU}\right|. \tag{5}$$

Conditions:

$$P_U + P_{RA} + P_{RU} = 1, \tag{6}$$

$$P_U \geq 0, P_{RA} \geq 0, P_{RU} \geq 0. \tag{7}$$

It is necessary to choose more time periods for optimization, so that the differences in hourly variations between different traffic characteristics are taken into account. Three time periods 5:00-10:00, 10:00-13:00, 13:00-23:00 have been chosen. In the first time period R_{TU} is expected to be considerably higher than reference shares for recreational cycling. For the noon period the highest share on daily counts is expected for recreational cycling not affected by workhours (R_{TRU}) and R_{TRA} is expected to be the most important in the afternoon.

3.3. Results description

Map in figure 5 shows calculated bicycle traffic characteristics for each counting location in Prague. The utilitarian cycling (violet) is rather more important in the central part of the city (places characterized by higher urban density and concentration of trips origin and destinations). Utilitarian cycling also dominates at the river banks which form natural barrier and ensure small trip elevation gradient.

Considerable share of recreational cycling not affected by workhours (green) was estimated for facilities in the proximity of downtown core (Dukelských hrdinů - 48,5 %, nábřeží Kaptána Jaroše – 28,5 % and Rohanské nábřeží – 10,6 %). This may be caused by more frequent occurrence of tourists who decide to enjoy the city by bike while spending their vacation in Prague. There are four more sections with high share (15 % – 29 %) of recreational cycling not affected by workhours which are not directly connected with the touristic areas.

Considerable share of recreational cycling affected by workhours (orange) was estimated for facilities in parks and also for facilities further away from the city centre. At the outskirt of the city the riverbanks seem to be popular locations for recreation of city inhabitants and less important for commuting (Modřany, Lahovičky, Radotín). However, this assumption needs to be supported by further research.

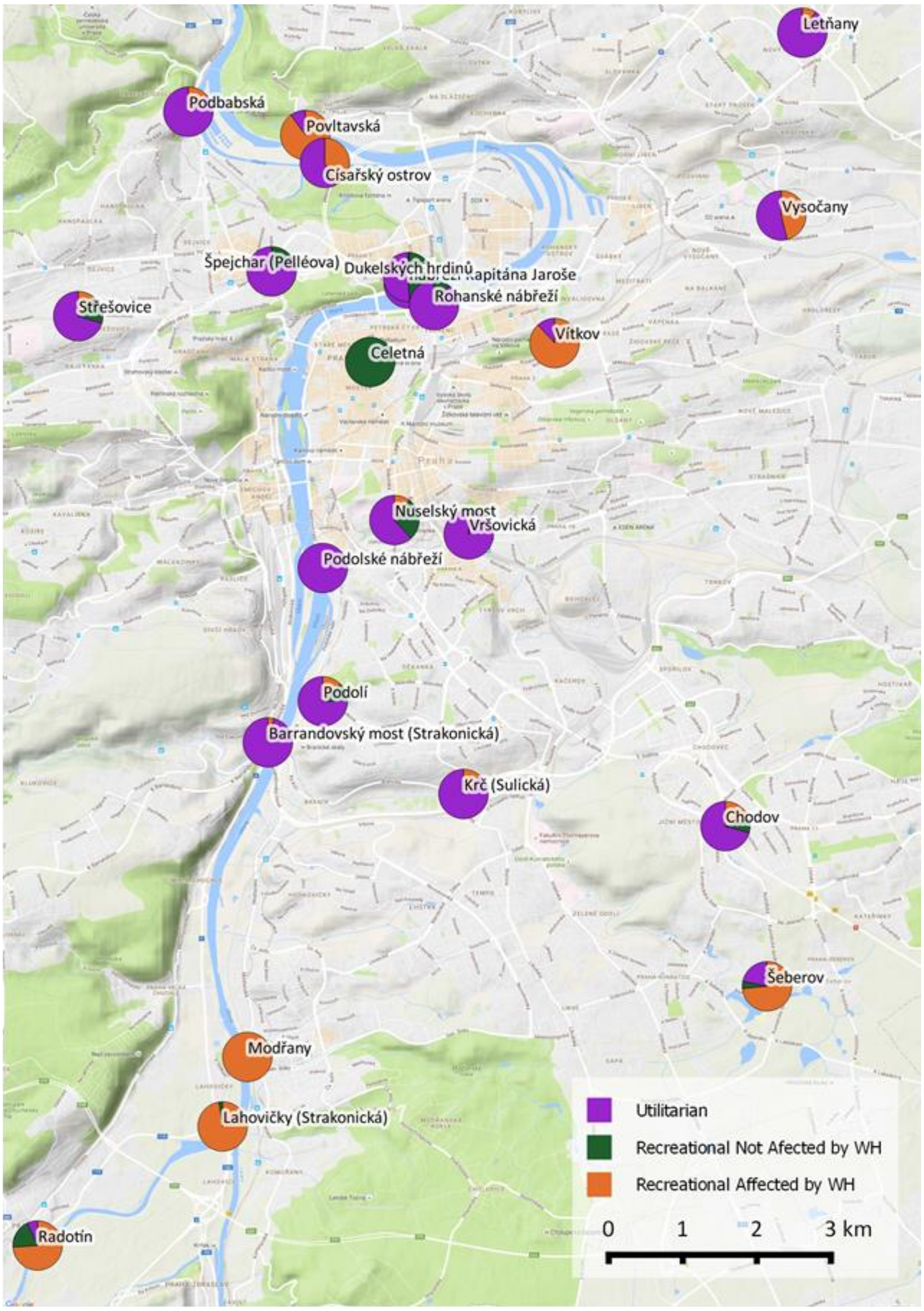


Fig. 5.
Calculated bicycle traffic characteristics for each counting location in Prague

4. Conclusion

In Prague 16 out of 23 counting sections were estimated to be predominantly utilitarian. This may be due to location selection and it gives no information about prevailing characteristics of bicycle trips made in Prague. The estimated representation of different traffic characteristics corresponds to expectations based on the analysis of the land scape of the city and built environment. Nevertheless, there are several sections with unexpected traffic characteristics (e.g. Nuselský most, Radotín). For better understanding to these exceptions, it is necessary to obtain more information about particular sections (e.g. interview locals and users, analyse trips and destinations of respective trips).
Results can be further used in infrastructure planning in Prague. Presumably different user groups (utilitarian/recreational) demand different type of infrastructure. The method used can be further implemented for yearly averages, so that changes in bicycle traffic characteristics in each section can be evaluated as well as overall changes in attitudes towards cycling. To assess these trends, more complex models need to be utilized reflecting other variables such as weather, season, special occasions (road closures, public transport strikes, etc.) etc.
Used method is based on evaluation of working-days hourly variations averages for the whole operating duration. In reality these variations change over the year as well as the traffic characteristics. It is also to be mentioned, that the used method provides no information on non-working-days traffic characteristics, which may not be in-line with working-days traffic characteristics (e.g. recreational cyclist may be willing to travel further during weekends).
The most uncertain part of the method is to estimate reference shares. Reference shares are calculated from the hourly variations in hypothetical one-trip purpose reference locations (see equation 3 and figure 4). In this case study, reference locations were approximated by selecting locations with the highest level of conformity with anticipated daily variations (described in previous chapter 3.1) and according to the knowledge of local situation. In reality reference variations may differ for each location and especially for different towns/cities/regions. Also the method used for calculation – optimization may provide only local optimums. For these reasons it is difficult to assess the confidence of obtained results.
The method introduced in this paper may be utilized in towns and cities which possess data from bicycle traffic counts (either continuous or manual). It is especially valuable for cities which have no information on travel behaviour and mode share (e.g. developing countries, small cities). It helps to estimate the importance of utilitarian cycling, which may be undervalued in regions with high share of recreational cycling (some people may perceive cycling as purely sporting activity). Obtained results provide important input into the strategic planning as well as infrastructure measure design. The method can be further included into more complex models which asses impact of other variables on bicycle traffic flows.

References

Brandenburg, Ch.; Matzarakis, A.; Arnberger, A. 2007. *Weather and cycling - a first approach to the effects of weather conditions on cycling*, Meteorological Applications, 1(14): 61-67.

CAMEA, spol. s r.o. 2016. BikeCounter data, Prague. Available from Internet: <https://unicam.camea.cz/Discoverer/BikeCounter/bc/index/bc/BC_KJ-HRHO>.

Cools, M. 2009. *Inter- and intraday variability of Flemish travel behavior*, Ph.D. Thesis, University of Hasselt.

Cools, M.; Moons, E.; Creemers, L.; Wets, G. 2010. *Changes in travel behavior in response to weather conditions: do type of weather and trip purpose matter?*, Transportation Research Record 2157: 22-28.

Cools, M.; Creemers, L. 2013. *The dual role of weather forecasts on changes in activity-travel behaviour*, Journal of Transport Geography, 28: 167-175.

Hamilton, J.M.; Maddison, D.J.; Tol, R.S.J. 2005. *Climate change and international tourism: A simulation study,* Global Environmental Change, 15: 253-266.

Jeuring, J.; Becken, S. 2013. *Tourists and severe weather – an exploration of the role of 'Locus of Responsibility' in protective behaviour decisions*, Tourism Management 37: 193-202.

Liu, Ch.; Susilo, Y.O.; Karlström, A. 2014. *Examining the impact of weather variability on non-commuters' daily activity–travel patterns in different regions of Sweden*, Journal of Transport Geography, 182(39): 36-48.

Liu, Ch.; Susilo, Y.O.; Karlström, A. 2015a. *The influence of weather characteristics variability on individual's travel mode choice in different seasons and regions in Sweden*, Transport Policy, 182(41): 147-158.

Liu, Ch.; Susilo, Y.O.; Karlström, A. 2015b. *Investigating the impacts of weather variability on individual's daily activity-travel patterns: a comparison between commuters and non-commuters in Sweden.* Transportation Research Part A 82: 47-64.

Liu, Ch.; Susilo, Y.O.; Termida, N.A. 2015c. Subjective perception towards uncertainty on weather conditions and its impact on out-of-home leisure activity participation decisions. *In Proceedings of the 6th International Symposium on Transportation Network Reliability, Nara, Japan.*

Miranda-Moreno, L.; Nosal, T. 2011. *Weather or not to cycle; whether or not cyclist ridership has grown: a look at weather's impact on cycling facilities and temporal trends in an urban environment,* Journal of the Transportation Research Board, 2300(500).

Tom, T.; Jaarsma, R.; Tutert B. 2013. *Exploring temporal fluctuations of daily cycling demand on Dutch cycle paths: the influence of weather on cycling.*

Technická správa komunikací hl. m. Prahy – Úsek dopravního inženýrství (TSK-ÚDI). 1988 - 2016. Annual report on transport, Prague. Available from Internet: <http://www.tsk-praha.cz/wps/portal/root/dopravni-inzenyrstvi/rocenky>.

PAVING THE WAY TO SUSTAINABLE MOBILITY

Eleni Anoyrkati[1], Vladislav Maraš[2], Mirjana Bugarinović[3], Stefania Paladini[4]
[1,4] *Coventry University Enterprises Limited, Priory Street, Coventry, CV1 5FB, United Kingdom*
[2,3] *University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11000 Belgrade, Serbia*

Abstract: National climate commitments to date will not be sufficient to keep global warming to below 2°C. Transportation has the highest growth of CO2 emissions of any industrial sector. The UN Conference in Paris (2015) recognized the importance to build more sustainable, green and smart transport systems. Increased environmental pressure impacts on a number of interrelated socio-economic and technological trends. Although mobility is essential to the functioning of European society it does, at the same time, presents major problems in terms of congestion, safety and environmental impact. Transport is a complex system that depends on multiple factors, including infrastructure availability, level of services, advances in technology, socio-economic needs (European Commission, 2009). The performance of the transport system is influenced by several different key drivers and has itself an effect on mobility, passenger transport and corresponding framework developments in the future. In order to understand all the significant relationships in context, one has to consider the key drivers that have an effect on changing mobility behavior and the transport system. Therefore this paper presents the results of an analysis of the future trends based on demand/behavior factors. For the forecast of trends, the Delphi Method was used to identify key mega-trends, the most predominant of all proved to be the 'Development of large metropolitan areas' which according to the participating experts is expected to be the most challenging trend with a great impact on mobility. Delphi method is also used to determine the relation between the selected key drivers grouped in clusters representing the social, economic and environment trends. In this paper, sustainable mobility is defined as: "A sustainable transport system is one that is accessible, safe, environmentally-friendly, and affordable" (Ministers of Transport, 2004).

Keywords: sustainable mobility, transport trends, Delphi method, trend clusters.

1. Introduction

According to the EEA (2016), transport accounted to a quarter (25%) of total GHG emissions and slightly more than a quarter (27.9%) of total CO2 growth rate of GHG emissions in the EU28. Although mobility is essential to the functioning of European society it does, at the same time, presents major problems in terms of congestion, safety and environmental impact. Traffic congestion, for example now affects about 10% of our major road network and costs estimates to €50 billion per year, or 0.5% of EU GDP (Papí J, et al, 2007). In the EU, compared with 1990 levels, no other sector has the growth rate of greenhouse gas emissions (GHG) as have been as high in transport.

Decision makers and stakeholders in the field of transport and mobility are facing challenges due to changing framework conditions. A demographic change is taking place in Europe and the demand for mobility is increasing. At the same time the energy consumption, emissions and costs should be reduced and access to mobility should be provided for all. Sustainable planning and practice is seen as a solution for future challenges even and at the same time the principles of sustainability are controversial and have to be negotiated by relevant stakeholders. Decisions should be based on current changes and trends while at the same time include the future requirements. The need to plan and decide according to the trends for the future is especially challenging in the field of transportation as the cost-intensive infrastructure requires long-term planning and investment.

This paper aims to provide an overview of the most important trends and overall relationship between key drivers that are expected to influence the transport system in the short term (2030) based on experts' opinion received by applying the Delphi method. This is envisaged to support policy making in terms of deciding directions for future Research and Development investments in order to ensure a greener, integrated and more sustainable transport system in Europe. Sustainable mobility is understood as a long term vision that needs to be achieved in the context of achieving a more inclusive and competitive society and economy in a continuous changing context.

2. Transport factors and trends (literature review and status quo)

The interaction between supply and demand of transport determines system performances and mobility patterns. The way the transport system performs generates impacts which can be compliant or not with sustainability criteria. External key factors and policy actions interact within the passenger transport system. External key factors relate to those variables, which are not specific to the passenger transport system, but have impacts on it and contribute to shape its development. They include socio-demographic and cultural factors, economy, environmental and technologies. Policy actions are the fundamental instruments used to coordinate and steer the development of social and economic systems and naturally the development of transport systems. Therefore, policy actions have impacts on the development of both external key factors and passenger transport system key characteristics.

2.1. Social trends

Globalisation is recognized as a major driver of **urban sprawl**, fostered by the development of ICTs, along with increased accessibility (EC, 2011). The rapid increase in globalisation has been accelerated by cheap transport and the

[1] Corresponding author: e.anoyrkati@coventry.ac.uk

massive growth in communication systems. It is anticipated, however, that the **political and economic crisis** (which started in 2008-2009), and the delays in trade negotiations, could hinder further globalisation in the short term. Recent years have witnessed economic growth, rising average incomes and improvement in the quality of living. Regional **disparities** such as economic specialisation or different rates of growth of employment influence mobility demand (Rosenbloom, 2002). The **centralisation** of economic activity in cities and **agglomeration**s goes along with decline of rural regions (Cervero et al, 2006). Cities as well as specialised regions with complementary functions have to be served by high-quality transportation links. As one main important factor, **income** enables actors to choose conditions and areas for living as well as the transportation mode connecting them to work. The result can be more or less traffic; for example sub-urban residents drive more and walk less (Cao et al., 2009). Depending on oil price movements and mobility price development, social exclusion via poor accessibility due to rising real oil prices might increase; even more so if income disparities are increasing as well (Currie and Stanley, 2008). The EC document on a *Sustainable Future for Transport* (EC, 2009) has identified **urbanisation,** a key trend of the last three decades, and its impacts on transport as one of the main challenges in making the transport system more sustainable. In general people will live longer, be better educated and **emigrate more** (EEA, 2011). An increase in the share of the population over 65 is expected in future, especially in the European Union; **demographic ageing** is one of the most important trends challenging transportation policies and planning (Lisiankova, 2005).

2.2. Economy trends

Income raise and sustainable mobility rely on a stable, if not growing, world economic outlook, without which some of the ambitious aims will be seriously hampered. While the announced recovery in 2014 has strengthened in 2015 and 2016 and it is expected to continue in 2017, forecasts are less optimistic than in previous assessments. As of Spring 2016 (IMF, 2016) the expectations of global growth for 2016 have already been revised 0.2 % down since the beginning of the year, setting at 3.2 % like the year before. As a matter of fact, the recovery, driven primarily by emerging market and developing economies, proved not to be as strong as previous data suggested, given increased uncertainty of various kind (political first of all, with the Brexit and the US Presidential Elections in November 2016). Also, worsening internal conditions of countries like Brazil and Russia have not helped in this sense. Growth in the EU, one of the main areas of interest for sustainable mobility thanks also to the funding committed by Horizon 2020 to the development of circular economy, remains flat at 1.5% overall, and forecasts for 2017 gives the Euro area at a 1.6% of increase (IMF, 2016). Global trade seemed as well less sustained as previously expected, in absolute terms (2.8% in 2016, same of last year) and in ratio of GDP growth, which is more worrying, highlighting structural weaknesses. While it should pick up momentum in 2017 (WTO, 2016) it will remain still far away from the 5% growth averaged in the 1990s. Also, the modest growth in quantity contrasted with the sharp decline in US dollar value, mainly due to fluctuation in commodities and energy prices and to the renminbi depreciation.

This is confirmed by recent national data of Chinese import-export surprisingly negative in July 2016 (The Economist, 4 August 2016), which hint to a slower manufacturing output in the country partners and in a dip in internal consumption in China’s domestic market. The so-called rebalancing of the Chinese economy, and that sees the transition of China from an export-led country to a more mature system internally driven, is proving less smooth than initially deemed, and it can destabilize world recovery in the following years.

2.3. Environmental trends

In a scenario building exercise on the future of transport, it is essential to take into consideration the variables introduced by environmental factors such as climate change and the overall energy outlook, both in terms of fossil fuel prices and renewable energy development. The effect of climate changes are visible everywhere. "The human influence on the climate system is clear and is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system." (IPCC, 2015). However, steps have been taken after the undoubtedly successful United Nations’ 2015 Climate Change Conference (COP21), where all countries have finally committed to reducing their greenhouse gas emissions according to a scheme called Intended Nationally Determined Contributions (INDCs) and to transiting from a fossil-fuelled economy to one of clean energy. Years of effort have already contributed to reduce that share from 50% in 1970s to 30% in 2015 (WB, 2015).

Table 1
World energy usage (2013) – Millions of tons of oil equivalent

Energy Source	Power Generation (electricity and heat)	Final Consumption			Total Primary Energy Demand
		Industry	Transportation	Buildings	
Coal	2,404	768	3	128	3,929
Oil	284	302	2,357	317	4,219
Gas	1,172	557	96	627	2,901
Nuclear	646	–	–	–	646
Hydro	326	–	–	–	326
Bioenergy/Biofuels	155	194	65	861	1,376
Other Renewables	127	1	–	32	161
Electricity and Heat	–	842	26	1,040	...
Total	5,115	2,664	2,547	3,004	13,559

Sources: International Energy Agency, *World Energy Outlook* and *World Energy Balance*; and IMF staff calculations.

All this happens in a circumstantial outlook of declining commodities and energy prices since at least one year. As a matter of fact, the Primary Commodities Price Index has declined 19 % since August 2015 (WEO, 2016), especially metals, due to a slowdown in China's demand.
Reduction in oil prices is even more substantial, having stumbled down by over 70 % since June 2014, and by 32 % in the same period considered above (OPEC, 2016). Moreover, the forecast hints at a further reduction, with the world global demand in 2017 expected to fall by 1.2 mbd (IMF, 2016). Low oil prices, while generally constituting good news for economy and transport, can however represent a double-edged sword when it comes to curb emissions and invest in a more sustainable mobility framework, reducing some of the incentives to develop alternative, and cheaper, solutions.

2.4. Technological trends

The increased use of **Information and Communication Technologies** (ICTs) in transport is one of the emerging trends in urban mobility. According to Lee-Gosselin et al., (2009) '*a key characteristic of this trend is a ``post-modern" complexity, in which mobility is a reflection of expanding spatial and temporal choice, and of "on demand" consumption*'.
The trend towards more cooperative transport systems and new types of mobility requires new types of ICT technologies and new ways to exploit existing ICT technologies. Integrated multimodal travel information (IMTI) systems offer time savings (travel and search time) and effort (physical, cognitive, and affective) savings. During the pre-trip stage the passenger collects IMTI in order to plan multimodal travel; desired IMTI types in this stage are used to plan the part of the journey that is made by public transport. Wayside IMTI is most useful when it helps the traveller to catch the right vehicle en route. (Grotenhuis et al., 2007).
Communication between vehicle to vehicle or vehicle to infrastructure is also important in facilitating commuting and supporting co-modality. Kantowitz and Le-Blanc (2006) identified the following types of communication: 1. vehicle-to-vehicle (V2V), 2. vehicle-to-infrastructure (V2I), 3. infrastructure-to-vehicle (I2V). A large range of ICT technologies could be used as underlying technologies for these different types of communication between vehicles and infrastructure. Some examples mentioned by Kantowitz and LeBlanc (2006) are: WiFi, radio frequency identification (RFID) tags and infrared (IR), DSCR (dedicated short range communication) and cellular data connections (3G or 4G).
Expected developments in ICT technologies may also result in changes in mobility services offered and types of mobility. An important trend that is expected by many experts is autonomous driving based on vehicle-to-vehicle and infrastructure-to-vehicle communication; autonomous vehicles will become available in the future. (Giannopoulos, 2004).
A further trend that is anticipated to take on major importance in the future is the increased use of car sharing services supported by ICT applications. This trend is encouraged by the social trend of a shift from private ownership to shared use of vehicles. As stated at the transportation sustainability research centre's (University of California, 2012) report, carsharing schemes have grown drastically over the last years: point-to-point car sharing counted 346,610 members in 2006 while this number was increased to 1,788,027 members in 2012.
A major improvement in fuel economy is projected by 2020 due to improved **propulsion and vehicle technologies,** including weight reduction. The World Energy Council report (2011) projected the technology mix for cars was for the period from 2015 to 2050, including years 2020 and 2030 for two scenarios: a "freeway" scenario in which pure market forces prevail to create a climate for open global competition; a "tollway" scenario where governments decide to intervene in markets to promote technology solutions and infrastructure development that puts common interests at the forefront. Shell (2009) has analysed the fuel consumption of different types of propulsion systems with projections until 2030 (petrol and diesel, with and without hybrid-propulsion) in two scenarios: the trend-scenario in which primarily conventional and simple technology is used; the alternative-scenario in which technical developments (like downsizing of engines, new transmissions, better aerodynamics, lightweight constructions etc.) are taken into consideration. In the

trend-scenario, average fuel consumption of the vehicle stock is projected to decrease from 7.8l/100km in 2006 to 6.1l/100km (22% less than the consumption in 2006) in 2030. The alternative-scenario shows a more significant reduction up to 5.2l/100km (41% less than the consumption in 2006).

2.5. Policy trends

The EEA (2008) study, outlines as vital to increase coordination between all policies affecting the environment, such as **transport policy and planning** while the future promotion of reforms to favour the share of **sustainable mobility** should be outlined (Colonna 2009). The **internalisation of external costs** (externalities) is integrated in the list of policy measures designated as “smart pricing and taxation”. The White Paper “Roadmap to a Single European Transport Area” (EC, 2011) illustrates the EU objectives for the internalisation of externalities.
EU has issued the Directive 2002/49/EC relating to the assessment and management of **environmental noise** stress on the strategic noise mapping. Member States must draw up action plans designed to manage, within their territories, noise issues and effects. Member States must also **involve the public** in the action plan development (CEC, 2008). The vast majority of energy taxes are being levied on (mostly road) transport fuels (EC, 2009a). Policy measures envisaged in the White Paper are to (EC, 2011): “establish a link between vehicle **fuel taxation** and environmental performance; to full **internalise the cost of GHG** emissions for all modes of transport in a co-ordinated and stepwise manner; assess the possibility of introducing **VAT** on all international passenger transport services inside the EU; promote a revision of company car taxation to eliminate distortions or, as a second best, to **provide incentives for clean vehicles.** Europe’s future is said to depend on cities resilient to climate change and, this need will include assuring a r**esilient transport** for the future of European urbanized areas (EEA, 2012). On the other hand, transport adaptation to climate change will require specific policy instruments **and investment in a low-carbon economy** (CoR 2011).
The diverse structures of passenger car taxation in Europe were analyzed by Kunert and Kuhfeld (2007). **Taxes and fees** related to the registration, ownership and use of cars are assessed differently across Europe, and their rates vary significantly.
Infrastructure projects include the European global navigation satellite systems (Galileo and EGNOS), which will complement the 'traditional' networks and improve their exploitation” (EC, 2009). The Trans-European transport networks policy has much increased the **coordination** in the planning of **infrastructure projects** by the Member States. The extension of the **TENs** to cover the new Member States, building on the investment already made prior to enlargement, has provided the blueprint for **Structural and Cohesion Funds** to gradually fill their infrastructure deficits. Significant changes in **urban mobility** require comprehensive actions that bring together **land-use planning**, **road use and parking, transport pricing, infrastructure development, public transport policy** and much more (EC, 2011b).
The development of **decentralised economic activities** will require an efficient, flexible and intermodal transport system. The current situation in terms of accessibility in the EU suggests that there is a marked division between central and peripheral areas as regards their transport connectivity and costs as a result of geography and patterns of economic activity (Christidis and Ibañez, 2010).

3. Methodology

A wide range of methodologies were applied in this paper: desk study, surveys, interviews and Delphi analysis.
The research started with a literature review on the most important trends in order to enable us draft a list of the most predominant mega trends that were included in the questionnaire. The survey questionnaire was designed based on the results of the literature review where the trends included there consisted of the ones that were cited the most. The Delphi expert questionnaire was applied in order to estimate the key megatrends on passenger mobility volumes and patterns. Based on the Delphi results, relationships between the mega trends were defined.

3.1. Delphi method

The **Delphi technique** is a widely used and accepted method for gathering data from respondents within their domain of expertise. The technique is designed as a group communication process which aims to achieve a convergence of opinion on a specific issue. The method consists of a series of repeated interrogations, usually by means of surveys. After the initial interrogation of each individual, each subsequent interrogation is accompanied by information regarding the preceding round of replies, presented anonymously. Thus, experts are encouraged to revise their earlier answers in light of the replies of other participants. In this way, the group may converge to a broadly supported opinion. The final position of the group is determined by averaging the individual opinions after the last round.

In this study the Delphi approach will consist of a two-round online survey :

1. *Online survey – Round 1*; based on the results of the assessment on key drivers and megatrends with respect to mobility patterns an online survey was developed to gather the opinions of experts on the importance of the various megatrends and their impacts on mobility patterns. Before inviting all stakeholders to fill in the survey, the online

survey undertaken by a selected group of stakeholders. In this way we can make sure that the survey will be understood by the participants.

2. *Online survey – Round 2*; based on the results from the first round of the online survey a second round of the online survey was developed. This second round of the survey resulted on a more concrete list and shorter of the most predominant Megatrends. Preliminary definition of the relationship between them was done based on the obtained Delphi results.

The questionnaire was answered by more than fifty renowned experts on a Pan-European level.

4. Results

The objective of the first expert online questionnaire was to collect expert opinions on:
1) the importance of critical factors in terms of their impact on passenger mobility;
2) factors that were not found in the literature review

The questionnaire consisted of 10 groups of factors, which relate to the following influential areas:
1. Demographics;
2. Behaviour ;
3. Spatial organisation;
4. Economy;
5. Social structures;
6. Globalisation;
7. Environment;
8. Institutional structures and policies;
9. Transport policies;
10. Information and Communication Technologies;

Experts were asked to rate: the importance of each factor in terms of its impact on passenger mobility from the scale of "Not at all important" to "Extremely important".
Since only a selection of critical factors for each influential area was provided, experts were given the possibility to suggest up additional factors that they might consider critical and that were not already included in the list. The questionnaire was filled in by 59 high calibre experts representing the industry, academia, policy makers and also the European Commission.

The table below shows how scores have been assigned to the degree of importance in order to perform calculations.

Degree of Importance	Score
Not at all important	1
Slightly important	2
Moderately important	3
Very important	4
Extremely important	5

As demonstrated in the table 2, demographics have been rated on average as being very important to extremely important. The level of consent, estimated considering the value of the standard deviation, is good being in general around 1. The factor that stands an out is the ‘Ageing Society’ with average score 4.3 and low standard deviation (0.79) This factor has been also highlighted as one of the European Challenges by the EC, while measures to meet this challenge have been integrated in many policy documents as well as heavy investment on research has been put forward already.
Spatial organisation has also received high score for almost all factors. However, the factors that stand out the most are the development of large metropolitan areas and the urbanisation which have also received very good levels of consent
The table 2 below presents the twelve most important factors with the lowest deviation levels, as identified by the experts[2].

[2] In random order.

Table 2
Most important factors affecting passenger transport system

Trends	Factors	Score	Standard Deviation
Demographics	Ageing society	4.3	0.79
Spatial Organisation	Development of large metropolitan areas	4.41	0.9
	Urbanization	4.2	0.93
Economy	Financial recession	3.98	1
Social Structure	Unemployment rate	3.8	0.9
Globalisation	International Trade	3.75	1
Environment	Sustainable Development Renewable energy options	3.86 3.73	0.96 0.87
Transport policies	Charges (e.g. for congestion) Inadequate infrastructure investments Taxation of fuels Pricing	4.17 4 3.94 4	0.95 0.93 0.98 0.86

The experts were also asked to suggest factors that according to their opinion are important but they have not been included in the questionnaire. The great majority of the factors that were suggested by the partners were already included in the list above.
During the second round of the questionnaire, the experts were asked to rank the abovementioned factors that affect the major trends identified in the first round. According the majority of the experts the predominant factor that really affects sustainable mobility is the development of large metropolitan areas.
Chosen trends and factors, as indicated by the scores, are characterized with different influence on sustainable mobility However, the question is whether they act independently on the mobility? As some factors have similar characteristics they are grouped in three clusters i.e. social, economic and environmental trends (Figure 1). The primary goal of clustering is to measure the impact of social, economic and environmental trends to passenger perception mobility. In order to consider interdependence, based on Delphi results and subjective perceptions, relationships between trends and factors showing the degree of interdependence among them are drawn. Next, once the influence between the trends/factors was determined, interactions have been made until a consensus is reached. The process of solving the interdependence of key drivers of mobility is resulted with the relationship framework of trends/factors.

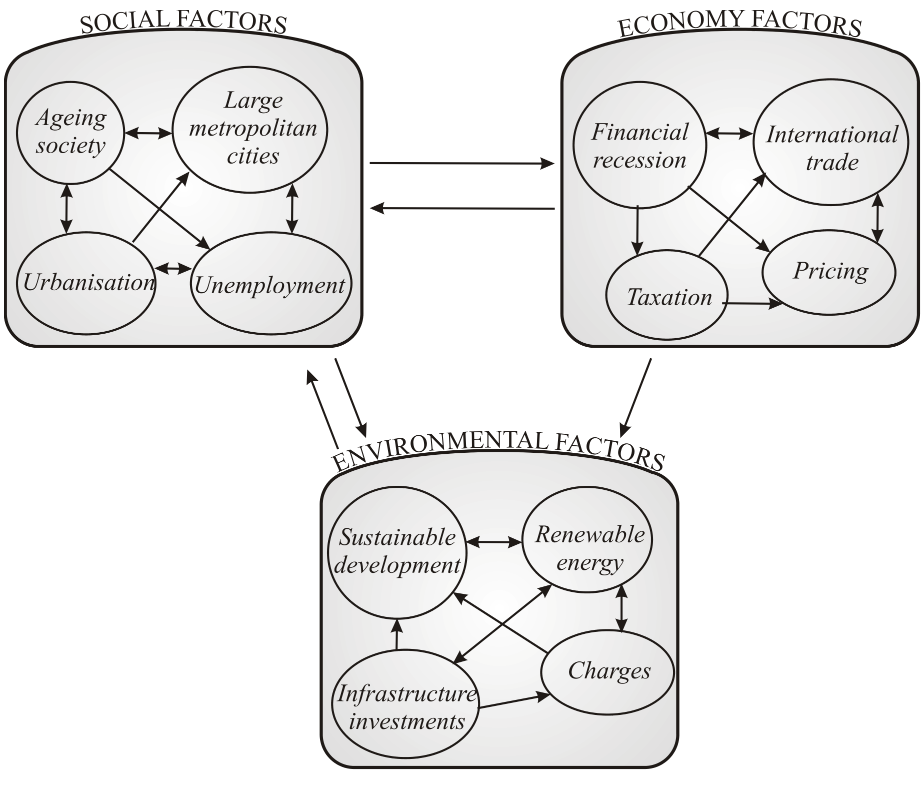


Fig. 1.
Relationship framework
Source: own elaboration

3. Conclusion

The goal of this paper is to identify key mega-trends or factors that are expected to impact the transport system in the short term (2030) and have a great impact on the mobility. These impacts can be compliant or not with sustainability criteria striving for an accessible, safe, environmentally-friendly, and affordable European transport. Identification of critical factors in terms of their impact on passenger mobility was based on experts' opinion received through application of Delphi method. Factors like development of large metropolitan areas, ageing society, charges (e.g. for congestion) proved, by the experts, to be the most challenging for the further development of the passenger transport system in Europe. In addition, based on the Delphi results, the relations between the selected key drivers, grouped in clusters that represent the social, economic and environment trends, were determined.

The future step in this research process will be determination of the degree of impact and influence between the trends/factors using ANP method or combination of more multicriteria decision methods. ANP is a more general approach to decisions that is a generalization of dependence and feedback relationship between elements to network system. By applying the ANP, it will be possible to determine the relative importance of a set of trends and factors in a problem of selection of sustainable mobility development scenario of the future passenger transport system. Therefore, interaction between factors and trends will be used for evaluation of different mobility scenarios. The aim of the scenario analysis and selection will be to highlight and make visible large-scale forces that push the future of passenger transport system in different directions.

References

Cervero, R.; Guerra, E. 2011. *Urban Densities and Transit: A Multi-dimensional Perspective,* Berkeley Centre for Future Urban Transport, Volvo centre of excellence.

Christidis P.; Ibañez N. 2010. *European transport policy: methodology to assess impact on accessibility*, Paper presented at 57th Annual North American Meetings of the Regional Science Association International, Denver, Colorado, 1013, November 2010.

Collona, P.; 2009. Sustainable Mobility and Transport - Mobility and Transport for Our Tomorrow Roads, *European Roads Review 14,* Spring 2009, RGRA.

Commission of the European Communities. 2008. *Directive relating to the assessment and management of environmental noise*, Directive 2002/49/EC of the European Parliament and of the Council, Brussels.

CoR. 2011. *Adaptation to Climate Change: Policy instruments for adaptation to climate change in big European cities and metropolitan areas*. European Union, Committee of the Regions, Brussels.

European Commission. 2009. *A sustainable future for transport: Towards an integrated, technology-led and user friendly system.* COM(2009) 279 final, Brussels.

European Commission. 2011a . *Whiter Paper: Roadmap to a Single European Transport Area-Towards a competitive and resource efficient transport system*. COM 144 Final, Brussels.

European Commission. 2011b. *IMPACT ASSESSMENT Accompanying document to the WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system*, SEC(2011) 358, Final, Brussels.

EEA – European Environmental Agency. 2008. *Beyond transport policy — exploring and managing the external drivers of transport demand. Illustrative case studies from Europe*, EEA, Copenhagen.

European Environmental Agency. 2009. *Towards clean and smart mobility: transport and involvement in Europe*. Copenhagen.

European Environmental Agency. 2012. *Urban adaptation to climate change in Europe*, Report nº2/2012, EEA: Copenhagen.

European Conference of Ministers of Transport. 2004. Volume 1, Activity of the conference, resolutions of the Council of Ministers of Transport and reports approved: annual report

Giannopoulos, G.A. 2004. The Application of Information and Communication Technologies in Transport, *European Journal of Operational Research* 152(2): 302-320.

Grotenhuis, J.; Wiegmans, B.W.; Rietveld, P. 2007. The Desired Quality of Integrated Multimodal Travel Information in Public Transport: Customer Needs for Time and Effort Savings, *Transport Policy* 14(1): 27-38.

Kantowitz, B.H.; LeBlanc, D.J. 2006. *Emerging Technologies for Vehicle-Infrastructure Cooperation to Support Emergency Transportation Operations*. The University of Michigan Transportation Research Institute, Washington D.C.

Kunert, U. ; Kuhfeld, H. 2007. The diverse structures of passenger car taxation in Europe and the EU Commissions proposal for reform, *Transport Policy* 14: 306-316.

Lee-Gosselin, M.; Miranda-Moreno, L.F. 2009. What is Different about Urban Activities of those with Access to ICTs? Some Early Evidence from Québec, Canada, *Journal of Transport Geography* 17(2): 104-114.

Papi, J.; Halleman, B.; Antonissen, T.; Falco, F.; Vizcarra-Mir, B.; Dezes, L. 2007. *The socio economic benefits of Roads in Europe*, IRF Research Council, Brussels.

Rosenbloom, S.; Ståhl, A. 2002. Automobility among the Elderly: The Convergence of Environmental, *Safety, Mobility and Community Design Issues*. EJTIR 2(3/4): 197-213.

Shaheen, S.; Cohen, A. 2012. *Car-sharing Market Overview, Analysis and Trends*. Berkeley: Transportation sustainability research centre, University of California.
Shell. 2009. *Shell Passenger Car Scenarios Up to 2030 - Facts, Trends and Options for Sustainable Auto-Mobility*, Shell Deutschland Oil GmbH, Germany.
World Energy Council. 2011. *Global Transport Scenarios 2050*, World Energy Council, London.

PUBLIC TRANSPORT ACCESSIBILITY AND SOCIAL EXCLUSION: MAKING THE CONNECTIONS

Matteo Ignaccolo[1], Giuseppe Inturri[2], Nadia Giuffrida[3], Vincenza Torrisi[4]
[1,2,3,4] University of Catania – Department of Civil Engineering and Architecture, Italy

Abstract: Social exclusion is a condition affected by different factors: quality of life, low income, inadequate housing conditions, high crime rates, elderly age and ethnic/cultural minority are all crucial aspects that must be considered. The possibility to have a good access, in a spatial sense of the term, to work places, education and healthcare services is a key factor to achieve that the whole population could take part to the society. In many South Italy cities, access to opportunities is mainly guaranteed by private transport, since public transport supply and services are low quality. Public transport should have the main role to overcome the mobility difficulties faced by disadvantaged groups. Accessibility to destinations by public transport can be considered a proper indicator and a simple measure to assess the impact of changes in the transport system on potential users and to evaluate solutions to remove spatial barriers. Accessibility indicators can aid decision makers in the determination of those population categories that are socially excluded and they can also be used to improve transport urban service supply. In this paper transit accessibility measures are evaluated for an urban area using a GIS approach, taking into consideration socio – economic factors from CENSUS data. Moreover, Lorenz curve is used to measure how accessibility by public transport is redistributed among different categories as a result of different alternative transport projects; through the use of this methodology, the Gini coefficients provide a single measure of overall accessibility equity. Methodology is tested in a case study related to the city of Catania.

Keywords: sustainable transport, transport equity appraisal, urban transport, spatial and transport planning.

1. Introduction

In the last few years, cities have been developing fast in more complex and fragmented systems: the reorganization of residential areas, activities and metropolitan services, as well as and the increasing mobility, have distorted rhythms and social dynamics. Vehicular traffic flows and land occupation by parked cars create a barrier effect and a consequent decrease of the possibilities of socialization.

An early form of social exclusion is manifested when individuals possess a poor "mobility capital" (Borlini and Memo, 2011), i.e. their ability to move is reduced, so they are ousted from all those resources located outside of its space range. People too young, too old, unable to drive, or too poor to afford a car or a plane ticket become "second class" citizens, leaning on a public transportation is often unreliable.

Van Wee and Geurs (2011) define social exclusion as the tendency of some people or groups of people to be excluded from a certain minimum level of participation in regional activities in which they wish to participate. The complexity of the phenomenon is evident: it is very difficult to recognize and quantify a minimum level of participation; moreover, the barriers that prevent the ability to participate in civil society are many and not only related to the economic factor. With regard to the field of transport, there is a close relationship between accessibility and social exclusion. The latter is not so much due to lack of services and social opportunities, as to a lack of access to such opportunities.

Preston and Rajé (2007) suggest that social inclusion can be achieved through both the proximity to the activities and services you want (which does not require to support travel costs) and the ability to reach distant destinations within reasonable time, even if with high transportation costs, or both by an intermediate state between those presented.

Lucas (2012) says that inadequate access to transportation and social disadvantage interact more or less directly resulting in what can be defined as "transport poverty". This in turn causes the goods and essential services and opportunities for social interaction to become inaccessible and at the same time cut off citizens from decision-making processes. The social exclusion that results risks triggering a degrading vicious cycle that causes an increase in social inequalities and centralized transport.

One of the policies for the urban mobility of large cities should be to discourage the use of private car when it is not necessary in order to promote new travel behavior and incentives to carry out an extensive and efficient public transport network. While all this is feasible, it must also be assured that the activities and main services are easily accessible by every transport mode. Therefore, a close interaction between the location of urban opportunities and the planning of public transport and of the urban transport system as well is strictly required.

Many people experiment different obstacles to reach opportunities and services: from physical barriers (availability and accessibility of transport) to economic (cost of transport) or urban structure mobility constraints (services located in places which are difficult to access). Until these barriers will not be removed, a significant portion of the population will remain unable to move as they would and, therefore, their opportunities to participate in the life of the communities will remain poor.

Public transport may be able to reduce this mobility gap and therefore to favor social inclusion. In fact, when it’s not accessible by the weakest population groups and it’s unable to break down the barriers that do not allow the participation to social activities, public transport fails its primary goal: to give access to employment or educational opportunities, medical care services and entertainment venues. In summary, public transport should offer everyone the ability to move and therefore it’s a critical issue for social inclusion policies.

[3] Corresponding author: nadia.giuffrida@dica.unict.it

The city of Catania, a medium-sized city (300,000 inhabitants) located in the eastern part of Sicily in Italy, has been for years on the top position of the Italian city for the highest car ownership rate. It appears totally necessary to convert this car possession trend by improving the efficiency of the whole transport system that presents some critical issues as traffic congestion, limited public transport utilization, little diffusion of cycling and walking for systematic trips, inefficiency of the parking management, absence of city logistics measures.
In this paper the relation between transport accessibility and social exclusion will be investigated by means of an approach using Lorenz Curve and Gini coefficient that will evaluate the relative accessibility of census regions in Catania city; methodology will be applied to public transport network and will verify the effectiveness in social inclusion improvements of different transport scenarios.

2. Methodology

2.1. Measuring social exclusion

The equity policies in the field of transport must be supported by a large amount of socio-economic indicators, in order to meet the high level of disaggregation required by social exclusion data.
One of the methodological approaches in the literature is presented by Currie (2010), which makes use of GIS technology by combining the offer of public transport measures with social needs indexes and transport poverty.
The extent of the public transport for each zone is a function of frequency of service and access to stops distance estimated by GIS, while for deeper analysis of the demand for public transport, Currie proposes an aggregate indicator called Transport Need Index. The measure is composed of a summation of social disadvantage indices associated with different weighting, as showed in Table 1. Weights are estimated through a survey of users' travel behavior in the city of Adelaide (Australia), but may not be the same in the case of an Italian city, whose inhabitants have a different travel behavior. Anyway similar indicators can be used to test the correlation among social exclusion and accessibility to public transport.

Table 1
Social disadvantage indicators

Need indicator	Weight
Adults over 18 without cars (Census, 2010)	0.25
Persons aged over 65 (Census, 2010)	0.13
Persons with disabilities (Census, 2008)	0.13
Low income households (lower quintile) (Census, 2008)	0.13
Persons over 15 without a job (Census, 2010)	0.13
Students (Census, 2010)	0.13
Persons 10-18 (Census, 2010)	0.13

Source: (Currie, 2010)

Other indicators of social exclusion, showed in Table 2, are suggested by the Italian Statistic Institute ISTAT (2015):

Table 2
Deprivation index parameters

Parameter
Young people abandoning education and training pathways
Regional poverty index
Population living in rural areas
People at risk of poverty or social exclusion
People in severe material deprivation condition
Overcrowding
Businesses and non-profit institutions that carry out activities with social content
Rate of juvenile crime

Source: (ISTAT, 2015a)

2.2. Measuring accessibility

The concept of accessibility plays an increasingly important role in in transport planning as useful tool to measure the combined effect of locations' proximity and transport connectivity. At the same time, accessibility indicators can incorporate social issues when they measure the level of difficulty experimented by different categories of individuals to reach the economic opportunities or social interaction throughout the area.
However, drawing up a strict and unambiguous definition of accessibility is a complex task. One of the first scholars which considered its importance in the context of spatial planning was Hansen, who defined accessibility as "the potential of interaction opportunities" (Hansen, 1959).

A recent definition that highlights the mutual interaction between land use and transport systems has been provided by Geurs and van Wee (2004). According to the authors, the accessibility can be considered as the measure with respect to which the use of the territory and of transport systems allow groups of individuals to reach activities or locations by a combination of modes of transport.

From these and other definitions in the literature, four major accessibility components can be identified: land use, the transport system, the time factor and the individual dimension (Geurs and van Wee, 2004).

A classification of accessibility measures depending on land use can be done considering the place in question as the origin or destination of the travel. We can therefore distinguish the active accessibility (or origin accessibility), and the passive accessibility (or destination accessibility) (Cascetta, 2009):

- Active accessibility refers to the need to carry out the activities located throughout the area by a user that is in a particular place (generally the resident) and it measures the ease with which he can reach various destinations from an origin. It is useful in locating settlement decisions.
- Passive accessibility refers to the need for the various opportunities that are located in a certain area of the territory, to be achieved by the various users scattered throughout the study area. In other words, it measures the ease with which individuals, business and the services of a target area of the displacements can be reached by the users concerned. It is useful in the location decisions of public services and economic activities.

Most of the formulations in the literature refer to an urban accessibility of active type, whose indicator, in analytical terms, is generally a function of the number of spatial opportunities and the generalized transport cost. In particular, the accessibility indices based on gravitational models provide a measure of the continuous type which weighs the value of the opportunities with respect to a spatial impedance function. The impedance function reflects the effect of decreasing accessibility due to the increase of distance, travel time, or in general of the generalized cost of shipping.

The first application of the gravity model to accessibility measures is attributed to Hansen (1959), which suggested that accessibility across regions was directly proportional to the attractiveness factors (jobs, shops, sports centers, etc.) and inversely proportional to the travel time between the zones, which represents the cost of moving. The Hansen's index has the following form:

$$A_i = \sum_j^n O_j \cdot f(C_{ij}) \tag{1}$$

Where Oj is the number of opportunities in the zone j and f(Cij) the impedance function among zones i and j. A negative exponential impedance is often used, such as:

$$f(C_{ij}) = e^{-\beta \cdot f(C_{ij})} \tag{2}$$

With C_{ij} generalized cost of travel among *i* and *j* zone and β is a parameter related to the cost, estimated by choosing a destination model. The generic measure of cumulative opportunities can be considered a special case where $f(C_{ij})$ is equal to 1 if C_{ij} is less than the predetermined threshold; it is equal to 0 otherwise.

This type of indicators offers the advantage of requiring a relatively small amount of data (ease of processing and calculation), allowing to differentiate the areas of study and to derive the accessibility indices for each of them. They are particularly useful for assessing the potential of suburban residential areas in allowing access to activities such as shops, schools, workplaces, health care and other services.

2.3. Lorenz curve and Gini index

If we assume the existence of a correlation between accessibility and social exclusion, accessibility indicators can be linked to an economic index, such as the Gini coefficient (which can be calculated as a result of the Lorenz curve tracing) in order to verify the social equity of its improvements.

The Lorenz curve is a simple and effective graphical representation of horizontal inequality, since it was created as an aggregate measure of the distribution of wealth within the population. It lends itself to many applications, from education to biodiversity, quantities that can be combined through the population.

The horizontal axis (Fig. 1) shows the cumulative percentage of the population under examination (from 0 to 100%), sorted according to the increasing value of the indicator, while the vertical axis shows the cumulative percentage same indicator. In the economic field, it is mainly used as a graphical tool for the analysis of inequality of income distribution.

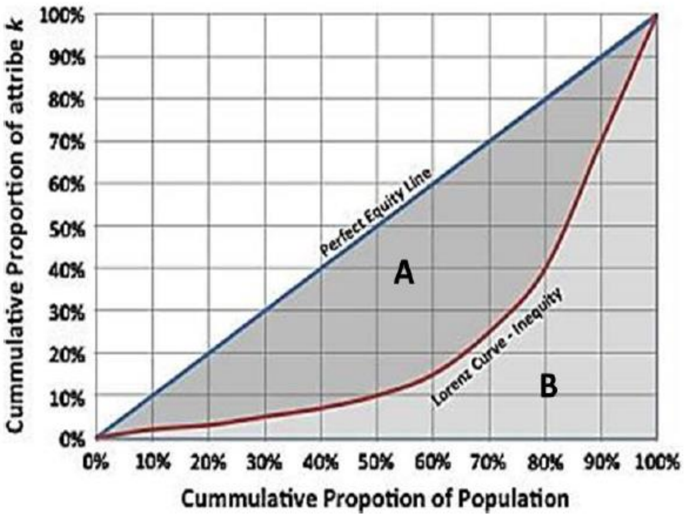


Fig. 1.
Lorenz Curve for a generic attribute k
Source: (Rofé et al., 2015)

In the transport field, social equity considerations are complicated by the fact that not only income plays a role, but also factors such as age, occupation, physical condition and the level of accessibility to services.
In this regard, the use of the Lorenz curve represents an original approach to provide a measure of overall accessibility compared to the entire population (Delbosc and Currie, 2011).
Basing on Fig. 2, Lorenz curve (in red) describes the actual accessibility distribution: each point of the curve indicates the percentage of accessibility owned by a given percentage of population. The blue line at 45° represents the line of equal distribution, i.e. the one corresponding to a perfect distribution of the same attribute. The more the Lorenz curve deviates from the straight line of equal distribution, the higher is the inequality of the distribution of accessibility in the population.
The Gini coefficient, introduced in 1912 by the Italian statistician Corrado Gini, is a mathematical measure of the degree of inequality, related to the area between the Lorenz curve and the straight line of equal distribution (indicated with the letter A in Figure 2). The relationship between this area and the area below the line of perfect equality (A + B in Fig. 2) is the Gini coefficient, which can be mathematically calculated using the following approximate formula in (3):

$$G = 1 - \sum_{k=1}^{n} (X_k - X_{k.-1}) \cdot (Y_k + Y_{k-1}) \tag{3}$$

where X_k is the generic interval of the cumulative percentage of the population variable and Y_k is the corresponding interval of accessibility cumulative percentage, for $k = 1, ..., n$ and $Y_0 = 0$, $Y_n = 1$.
Gini coefficient can take any value between 0 and 1. A value of 0 implies a situation of complete equality, while a value of 1 corresponds to complete inequality. The lower the coefficient, the lower the inequality of the distribution concerned.
The method described above is useful to analyze the changes over time of the distribution of accessibility in a given region, making it possible to see if inequality is increasing or decreasing. In addition, the Gini coefficient can be compared between different urban realities, obviously using the same methodology for the calculation of accessibility.
However, like any index of its type, it has the limit to remain unchanged if the accessibility of all individuals increases in the same proportion. In fact, being calculated from the relationship between two quantities, it cannot take into account the difference between the absolute values.

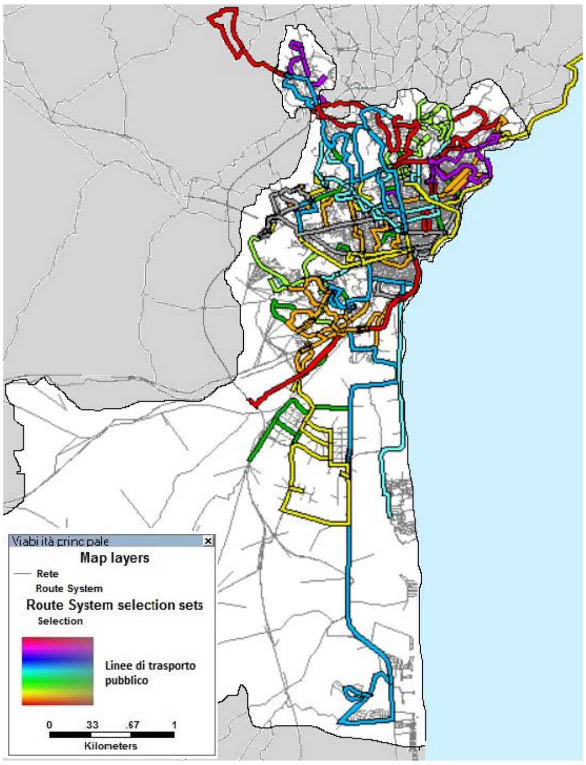
3. Case study

3.1. Territorial framework and transport supply

Catania is a city of about 300.000 inhabitants, located in the eastern part of Sicily (Southern Italy); it has an area of about 183 km*2* and a population density of 1.754,54 inhabitants / km^2 (Istat, 2015b). It's part of a greater Metropolitan Area (750.000 inhabitants), which includes the main municipality and 26 surrounding urban centers, some of which constitute a whole urban fabric with Catania. The main city contains most of the working activities, mixed with residential areas. With reference to the urban area, the transport service is provided by 51 bus lines, a Shuttle line (ALIBUS) connecting the city center with the airport and a second fast bus (called BRT1) connecting a park-and-ride facility on the northern periphery (Due Obelischi) to the city centre (Stesicoro Square). BRT1 is the first of three lines provided by the City of Catania with equipped lanes protected by curbs on the majority of their path and was promoted commercially as *Bus Rapid Transit*. In Catania it is also operated an urban subway line that currently connects the station "Porto" with the station "Borgo" from which continues as a surface long-distance railway line. By 2016 it is expected the undergrounding of the line until the station “Nesima” and it’s also planned the opening of a branch linking the station “Galatea” to Piazza Stesicoro.

3.2. Transport model and scenarios

A mathematical representation of the transport system has been built by the TransCAD modelling tool, a software which combines a Geographic Information System and a set of transport models in one integrated environment.
The zonation used for the city is the one given by ISTAT, which divides the study area in 2480 CENSUS sections. Three different scenarios have been analyzed. The first one, called Scenario 0 (Fig.2), includes 51 bus lines with a speed of 15 km/h; this will be considered as the current scenario and will be taken as base for the comparison with the other two transport solutions. The second one, called Scenario 1, provides for the introduction of three BRT lines and the subway line with the new extension from Borgo Station to Nesima station. The last one called Scenario 2, provides for an improvement of all bus lines speed from 15 km/h to 18 km/h.



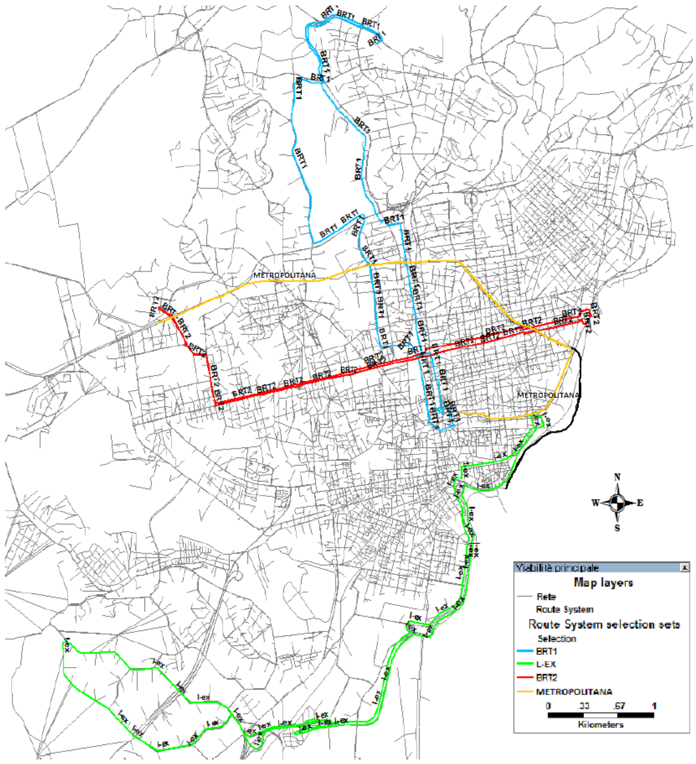


Fig. 2.
Scenario 0 on the left and improvements in the transport system of Scenario 1 on the right

3.3. Accessibility measures

Through the use of TransCAD software, Hansen accessibility measures have been evaluated for the three different scenarios.
The opportunities considered in the analysis include the accessibility of goods and services classified into: Health (hospitals, pharmacies); Education (University, schools, libraries); Places of worship (churches); Entertainment (theaters, cinemas, museums); Restaurants (Restaurants, bars, fast food); Transport services (metro, train station, bus stops). The Hansen Index has been evaluated considering as impedance a function based on the generalized cost of transport and taking into account parameters such as travel time, the cost of travel time, the number of transfers and considering a flat travel fare. The software provides standard values for deterrence index β, based on the selected transport mode and type of opportunities at destination. Values for our study are indicated in Table 3.

Table 3
Deterrence parameter for Hansen Accessibility Index calculation

Scenario	Mode	Destination	β Value
Scenario 0	Bus	Local Centers (No car)	0.082
Scenario 1 and 2		Local Centers (No car)	0.079

The active accessibility of the 2480 zones of the case study has been calculated for the 3 scenarios. Results show that the introduction of the improvements both in Scenario 1 and Scenario 2 provide an increase of accessibility; the amount of improvement for each zone can be deducted by the comparison of maps in Fig. 3, Fig. 4 and Fig. 5. The caption of the maps shows in brackets the number of zones that benefit from increased accessibility.

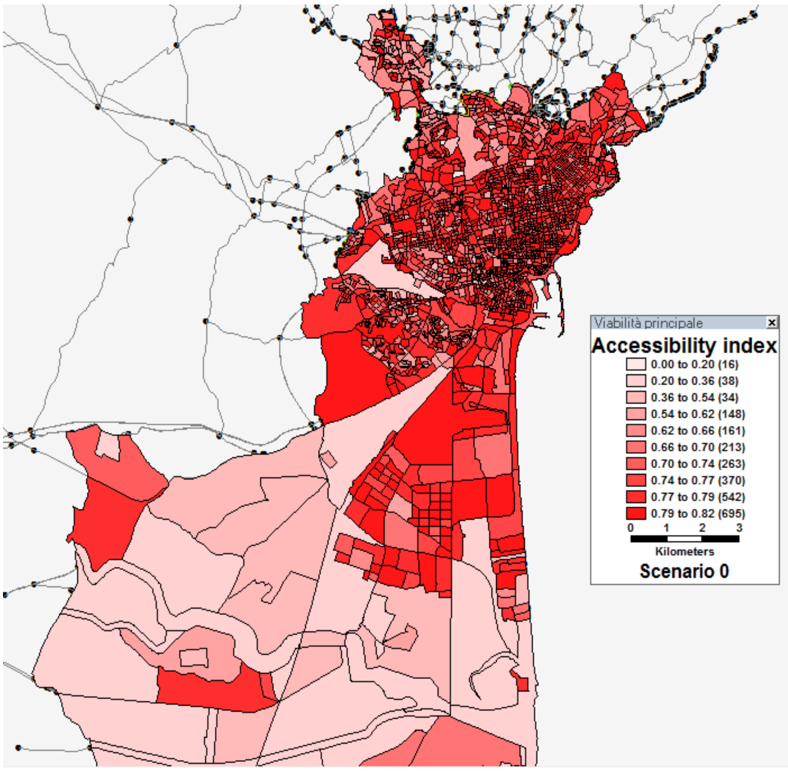


Fig. 3.
Accessibility Map for Scenario 0

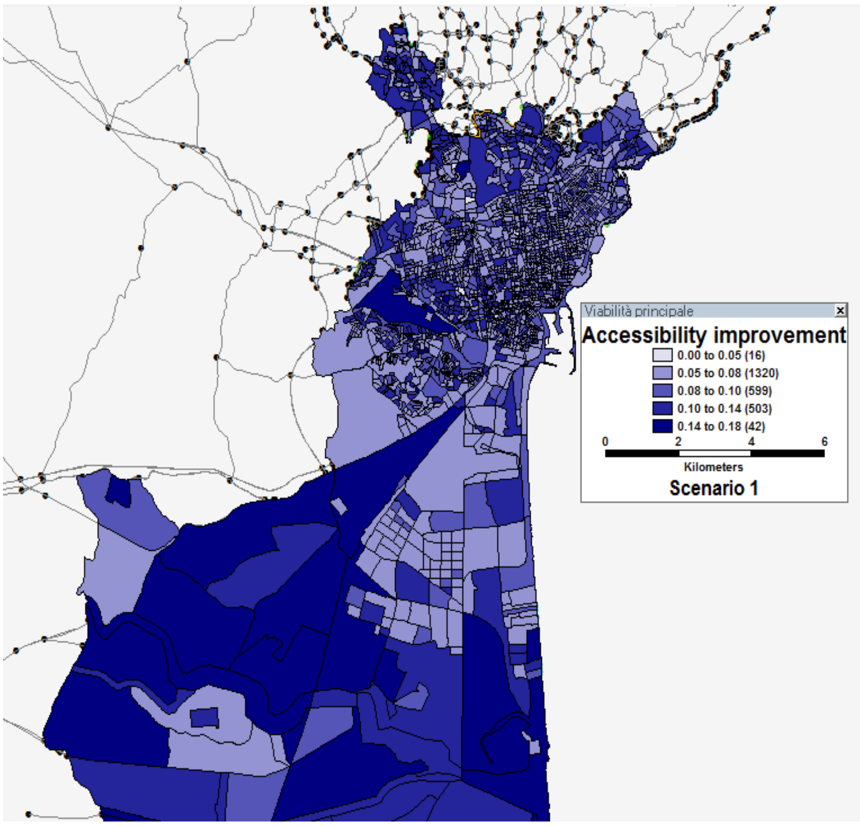


Fig. 4.
Accessibility Improvement Map for Scenario 1

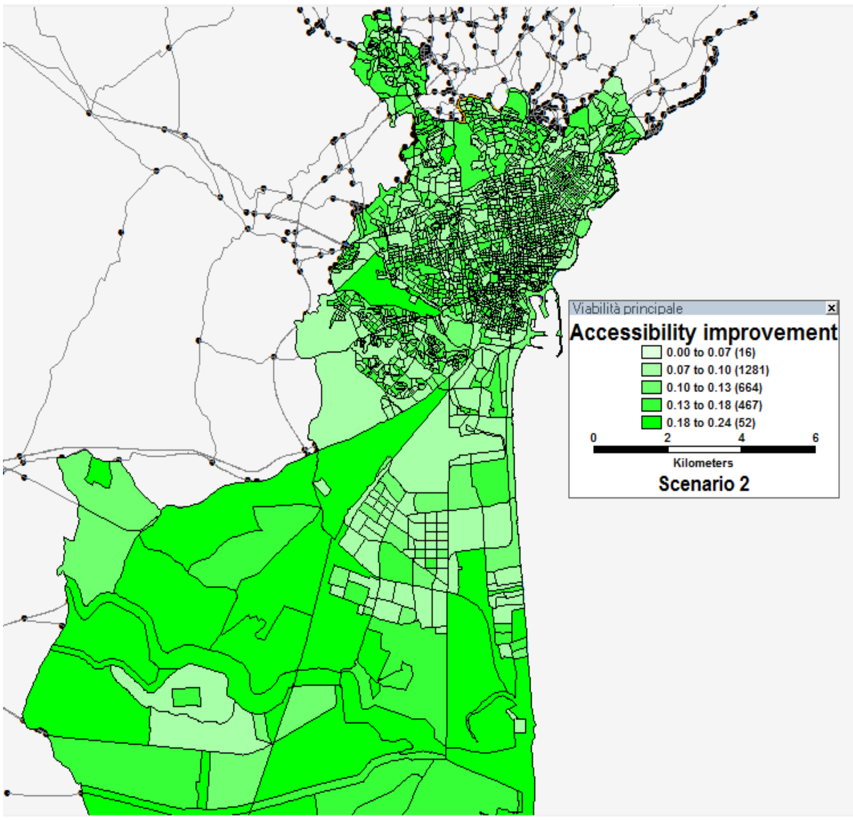


Fig. 5.
Accessibility Improvement Map for Scenario 2

3.4 Lorenz Curve and Gini Index

Lorenz Curve and Gini Index based on Hansen Accessibility measures have been calculated under the 3 scenarios. A graphical representation of Lorenz curves is shown in Fig. 6.
The Lorenz curves for all scenarios are close the perfect equality line (bisector). This does not imply a high level of service public transport, but a low inequality due to a quite uniform service coverage of the whole urban area. Both scenario 1 and 2 produce a significant improvement of equality as it is visible from the increased proximity of each Scenario's curve to the perfect equity line. The distribution of accessibility is quite the same for scenarios 1 and 2, so the relevant curves overlay each other.

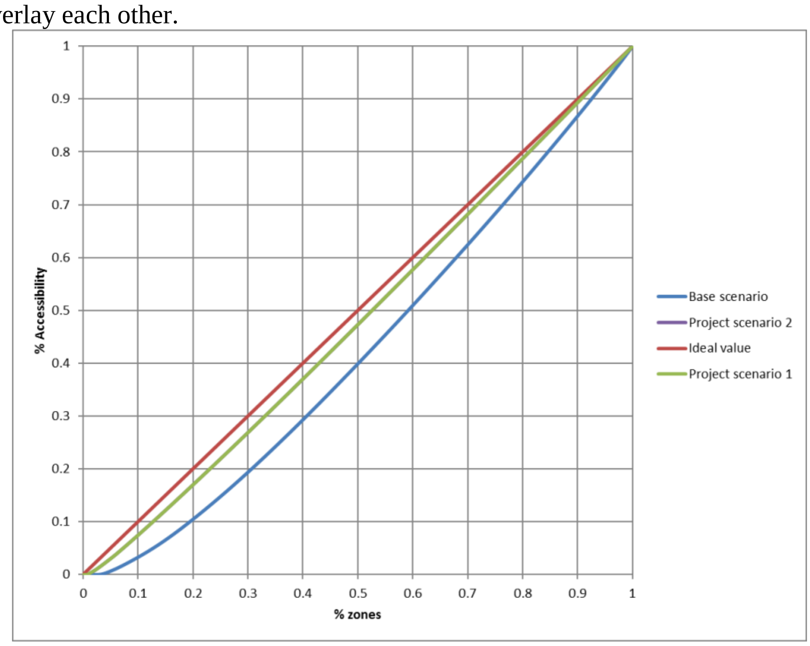


Fig. 6.
Comparison among Lorenz Curve for Scenario 0 and 2

Evaluation of Gini indices, which results are showed in Table 4, confirms the previous results and moreover underlines how Scenario 2 shows slightly better improvements than Scenario 1.

Table 4
Gini Index for the three different scenarios

Scenarios	Gini Index
Scenario 0	0.148485562
Scenario 1	0.046431085
Scenario 2	0.041428445

4. Conclusion

The ability to move and reach places even at great distances, has become an indispensable condition to live well and to integrate into today's society. Mobility is no longer just an option but has become a necessity. However, there are still many citizens who have limited resources or fewer resources than others, and the aim of social inclusion policies is to improve the quality of life of such the weakest sections of the population, in order to reduce exclusion.
Social inclusion is linked to the level of accessibility perceived by the individual, assessed according to the ease of reach of different places, with different availability of transport system. Accessibility awareness by citizens is a key element to coordinate the intervention measures in the field of transport and public services, but also to foster social receptiveness of such measures.
In this paper three different transport accessibility scenarios have been evaluated for the city of Catania. The application of an approach based on Lorenz Curve and Gini Index has showed that the proposed changes in the public transport network design corresponds both to an accessibility improvement and to a major equity of accessibility distribution as well. The methodology described seems to suit well to take decision in transport planning when both accessibility improvement and equity magnitude is crucial the address land use and transport decisions.

References

Borlini, B.; Memo, F. 2011. Mobilità, accessibilità ed equità sociale. In *Proceedings of the Espanet Conference: Innovare il welfare. Percorsi di trasformazione in Italia e in Europa*.
Cascetta, E. 2009. *Transportation System Analysis Models and Applications*. Springer.
Currie, G. 2010. Quantifying spatial gaps in public transport supply based on social needs, *Journal of Transport Geography*, 31-41.
Delbosc, A.; Currie, G. 2011. Using Lorenz curves to assess public transport equity, *Journal of Transport Geography*, 1252-1259.
Geurs, K.T.; van Wee, B. 2004. Accessibility evaluation of land-use and transport strategies: review and research directions, *Journal of Transport Geography*, 127-140.
Hansen, W.G. 1959. How accessibility shapes land use, *Journal of the American Institute of Planners*, 25: 73-76.
ISTAT, 2015a. Esclusione Sociale. Available from Internet: <www.istat.it/storage/politiche-sviluppo/Esclusione_sociale.xls>.
ISTAT, 2015b. Rapporto Urbes 2015. Il benessere equo e sostenibile nelle città. Available from Internet: <http://www.istat.it/storage/urbes2015/catania.pdf>.
Preston, J.; Rajé, F. 2007. Accessibility, mobility and transport-related social exclusion, *Journal of Transport Geography*, 151-160.
Rofé, Y.; Martens, K.; Eran, B.E. 2015. *Accessibility and Social Equity in Tel-Aviv Metropolitan Area - examination of the current conditions and development scenarios*.
van Wee, B.; Geurs, K. 2011. Discussing Equity and Social Exclusion in Accessibility Evaluations, *European Journal of Transport and Infrastructure Research*, 350-367.

NETWORK DESIGN AND PLANNING: SUCCESS FACTORS FOR HIGH QUALITY PUBLIC TRANSPORT

Slaven M. Tica[1], Predrag Živanović[2], Stanko Bajčetić[3], Branko Milovanović[4], Andrea Nađ[5]
[1,2,3,4,5] University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11000 Belgrade, Serbia

Abstract: Public transport network generally refers to a set of links, nodes, and lines that represent the infrastructure or supply side of the public transport system. Public transport network design depends on various factors, i.e. the city structure, the city transport network and infrastructure, geographical and climatic characteristics of the city, the structure of the public transport system, etc. Improving public transport network is one of the key steps in the process of creating high-quality and efficient mobility service. This paper deals with design of public transport network in urban areas. Emphasis is put on basic concepts and success factors in order to create high quality public transport services. Methodology for public transport network design and improvement, based on real transport demands and user requirements, is presented herein. The methodology represents a modern approach, which enables a continuous process of adaptation of the system in a changing environment. The proposed approach supports the realization of the efficient mobility of all categories of users, while at same time, increases system efficiency and effectiveness. The success in achieving these goals is measured using specific key performance indicators (KPI) for public transport network evaluation, which are defined herein. Proposed methodology is applied on the public transport system in Belgrade.

Keywords: public transport, network, key performance indicators (KPI).

1. Introduction

A vicious circle of the expansion of urban areas, overpopulation, and a lack of a quality life space smothers the cities and leads to a poorer quality of life. According to the official data of the UN, a staggering increase in urban population is expected in the next 30 years. Consequently, cities will face the inevitable socioeconomic, logistic and ecological challenges which will in turn make many commuters move from cities to suburbs causing the intensity of transport needs and transport demands to increase suddenly with respect to all modes of transport. While local authorities call for solutions aimed at the creation of livable cities (Vuchic, 1999), the time has come to recognize a long suppressed truth that public transport is by far the most efficient solution as regards the necessary quality of life and sustainable development of cities, and it is the key element of an efficient urban transport system (UITP, 2011).

Public transport (PT) system with its performances, technology, quality, costs and effects on the environment is one of the important factors which can influence size and structure of modern cities, their economy and sustainable development. The high quality PT system is foreseen to be the one of the key elements in the process of creating livable cities, because of its' ability to replace car use. Public transport is required to serve a range of objectives – from providing mobility to the disadvantaged through to alleviating traffic congestion – while also enabling efficient use of financial resources (Mees et al. 2010). These different objectives often conflict.

One of the basic elements of PT structure is transport network which presents, at the same time, the basis of transport system supply. Line network development is one of the first steps in the process of generating quality and efficient public service of citizens' mobility. Line network depends on the city structure, city transport network and its infrastructure (street network), PT subsystems structure, geographical and climate city region features, etc. General requests which urban public transport network should comply deriving from general PT system objectives refer to maximization of production and economic efficiency and system effectiveness and alignment of transport capacities with transport demand (utilization of the resources). Moreover, a high quality service to the passengers is required.

While there is an extensive literature focusing on PT systems economics and operation, the literature on the successful public transport network design and planning is relatively poorly documented. Furthermore, it mainly relates to the improvement of PT network on tactical and operational level. Therefore, urban and mobility planners are not well informed on the advantages of PT network planning and design and its' possibility to make a very significant contribution towards all above mentioned PT system objectives. Current practices reveal that there is a thin line between success and failure. The final outcome depends on the making the right or wrong choices on strategic level.

This paper outlines some basic principles of PT network design and planning. We aim to show that network planning and design can be a decisive factor for PT success. A methodology for public transport network design and improvement, based on real transport demands and user requirements, is presented herein. Proposed methodology is applied on the public transport system in Belgrade.

The remainder of this paper is divided in four sections. In the first section we concentrate on network planning philosophy and design principles. We continue with presenting the methodology for public transport network design and improvement. The methodology is applied in the PT system in Belgrade. The success in achieving PT network planning and design objectives is measured using specific key performance indicators (KPI) for public transport network evaluation, which are defined herein. Finally, some conclusions are presented. We also recommend some important planning and design principles (key lessons learned) for the public transport network.

[2] Corresponding author: p.zivanovic@sf.bg.ac.rs

2. Transport network planning and design overview

Urban public transport network or line network of urban public transport (PTN) is a sub-system of city transport network and it comprises lines network of all sub-systems (modes) of PT. The structure of the line network of the PT comprises static and dynamic elements. Static elements are the infrastructure of urban public transport network: routes, stops, terminal stops, stop distances and line lengths (network structure). Dynamic elements of PTN are the operation elements: times, speeds, number of vehicles, headways, frequency, capacity (scheduling) etc.

Thompson (1977) provided some early insights into the PT network planning. Furthermore, this issue has been analysed in detail by Mees (2000; 2010), Nielsen et al. (2005), Vuchic (2005), Dodson et al. (2011) and TRB (2015). Ronda and Mulley (2012) argued that influence of topography is often neglected in PT network planning. They claim that including this factor could led to better measuring the nature of the walk access; ensuring that planning guidelines measure walking access realistically; and choosing the most efficient mode topographically while ensuring that other policies support multimodal networks. Other group of researches focuses on scheduling problems in public transport systems rather than network strategy, structure and connectivity questions. A comprehensive overview this scheduling based network design and planning is given by Guihare and Hao (2008).

The essential purpose of PT is to carry a group of people with different trip origins and destinations in the same vehicle. As homes and workplaces become more and more dispersed, public transport faces an increasing challenge regarding the range of trip origins and destinations. It is a common assumption that public transport planning must be able to fulfill all these different users' travel demands and therefore it should be based on a very understanding of the different segments of the market. However, Mees (2000) have shown that this *demand-oriented public transport planning* might lead to some serious misconceptions. He names them the 'Bangkok' model of urban transport planning, which he connects with the idea of a liberal, deregulated PT market.

This have raised a question on whether the PT system should be planned as a widely distributed integrated transport network to support seamless multi-destination travel rather than as dedicated routes to meet specific passenger cohort demands (Dodson et al. 2011). Mees (2000; 2010) has demonstrated that the first concept (i.e. public transport systems as integrated networks) can generate higher levels of patronage than the planning of individual routes. This is due to the unexpected trip making behaviour that the network can support and which planners might not have predicted. Mees calls this phenomenon the 'network effect'. This new approach in public transport planning is often called *the supply-oriented planning*. Mees (2000) recommends the development of the public transport system according to the supply-oriented planning model of the Zürich region. Neilsen et al. (2005) gave guidelines on the strategies and tactics that can be applied to PT networks in order to achieve the 'network effect', based on analysis of some success and pitfalls in network planning. Dodson et al. (2011) distinct two basic principles underpinning the network effect. The first principle is to provide a simple and stable inter-connected network of public transport lines throughout the day with a structure and timetable that is easy for users to learn and understand (Nielsen et al. 2005). The second principle is to accept and support the fact that many of travelers will need to transfer between lines to access their selected destination. It can be said that transfers are the key to the 'network effect'.

Dodson et al. (2011) argues that planning public transport systems as seamless integrated networks, rather than as a series of individual routes serving a specified set of origin-destination pairs, is a critical task for metropolitan transport planning agencies. Although benefits of the supply-oriented planning model are undeniable, this approach can be economically unfeasible. Increasing frequencies implies additional vehicle fleet, more driver working hours etc. Therefore, cities with limited financial resources must look for modified solutions. Sustainable PT network development requires finding the right balance between demand and supply oriented planning. The choice of balance should reflect the major objectives of PT system, as well as the city objectives.

Throughout the years two different strategies in network design have emerged driven by the same currents as for PT planning (see above). The first approach is to provide 'tailor-made' services for different travel markets (express buses for peak hour trips; flexible paratransit for low-demand corridors and times, taxi for door-to-door demands etc.). The problem with this approach is that the more public transport is tailor-made, the more it surrenders its environmental and economic advantages (Mees et al. 2010).

The other alternative is the introduction of transfers can enable the provision of a 'ready-made' service. This approach enables 'anywhere-to-anywhere' travel, with high occupancy rates, by carrying different kinds of travelers on the same services (Mees et al. 2010).

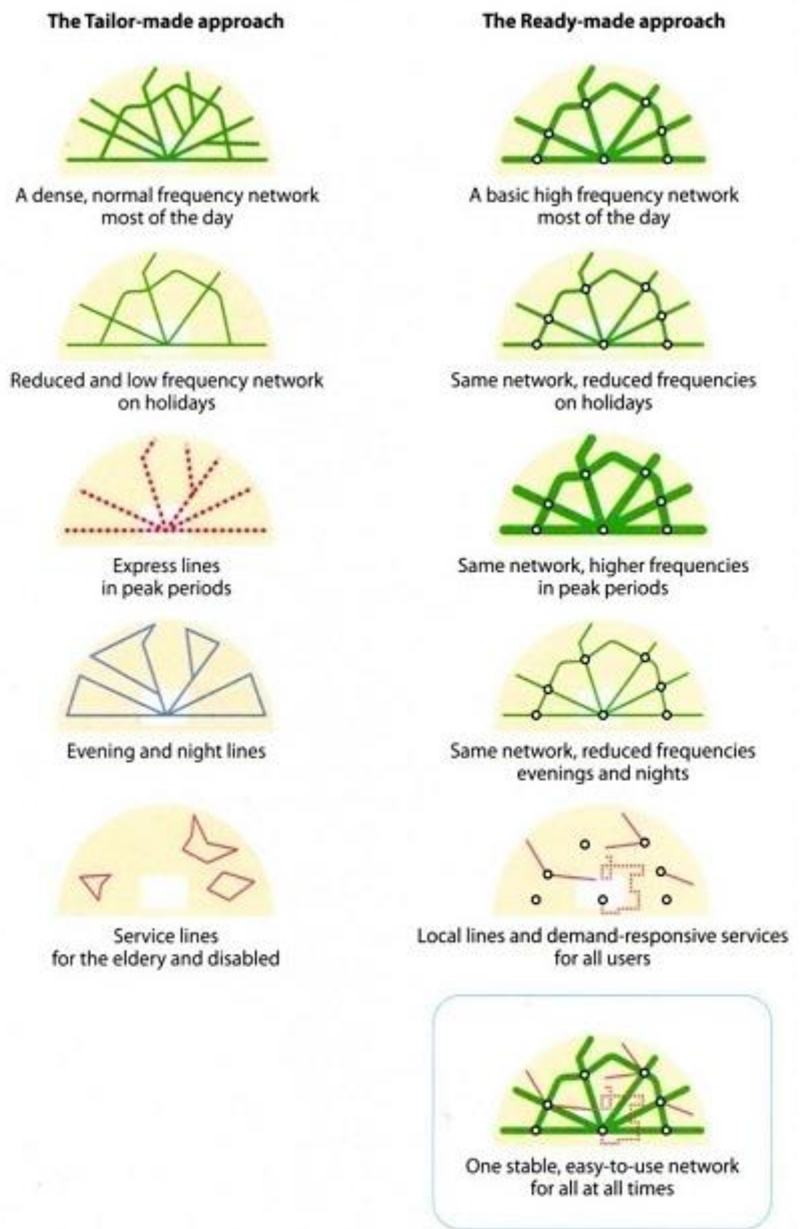


Fig. 1.
Two different approaches to network design
Source: Nielsen et al. (2005, p35)

The conventional PT network strategy is the one with radial links (Thompson 1977; Thompson and Madoff 2003). However, this strategy has some shortcomings. All trips are made via city center even though origin and destination might be in city suburbs. Thompson (1977) estimated that radially organised public transport systems in dispersed suburbanized cities can cater only to around 10 per cent of regional trips. An alternative strategy to the radial approach is the multi-directional network design approach (Newman and Kenworth 1999). Basic idea of this approach is to provide a seamless grid of mobility across as wide a proportion of the urban area as possible. Although performance level of these networks is higher compared to the simple radial ones, some disadvantages remain. To mitigate and/or overcome these shortcomings different kind of diametric PT networks, i.e. a network of pendulum lines running between areas on either side of the city centre. Bell (2016) identifies the benefits of the "network effect" and concludes that that the radial nature and centrality of PT networks in Australian cities may be more easily transitioned to a triangular rather than square geometry. Nevertheless, it is very unlikely to have a uniform type network in real urban systems. The same goes for the City of Belgrade (for details see following chapters).

3. The proposed methodology

Fig. 2 shows specific methodology for PT network planning and design. Developed methodology applies the system approach with real system data as basic inputs. Methodology represents a modern approach in designing the urban public transport basic elements which enables continuous process of constant adaptation to changeable environment. It comprises a number of steps and enables conditions for gradual changes in the system without leaps of sudden changes. The methodology was developed primary for the City of Belgrade, but is applicable to any PT system. Proposed methodology for PT network design and planning can be placed between the two previously indicated approaches (see Fig. 1). It follows the idea of high frequency urban and suburban transport network most of the day with reduced capacity on weekends and holidays. Basic network is supported with a network of local lines to cater to the diverse needs of passengers in suburban municipalities. After midnight until early morning hours a network of night lines completes the supply. This network runs through high-demand corridors and it is logically integrated with daily PT network (line numbers are the same, letter "N" is added to mark them as night lines). This has resulted in one stable, easy-to-use public transport network.

STEP 1: The first step of the methodology is the definition of objectives for PT network planning and design. PT system objectives can differ from city to city. Nevertheless, these objectives must be in line with the city's objectives. For the City of Belgrade and its' PT system target function is set as: "to cater all transport demand in terms of volume and quality for a defined level of costs (economic efficiency), with a maximum productivity of the system and the minimum negative impact on the environment".

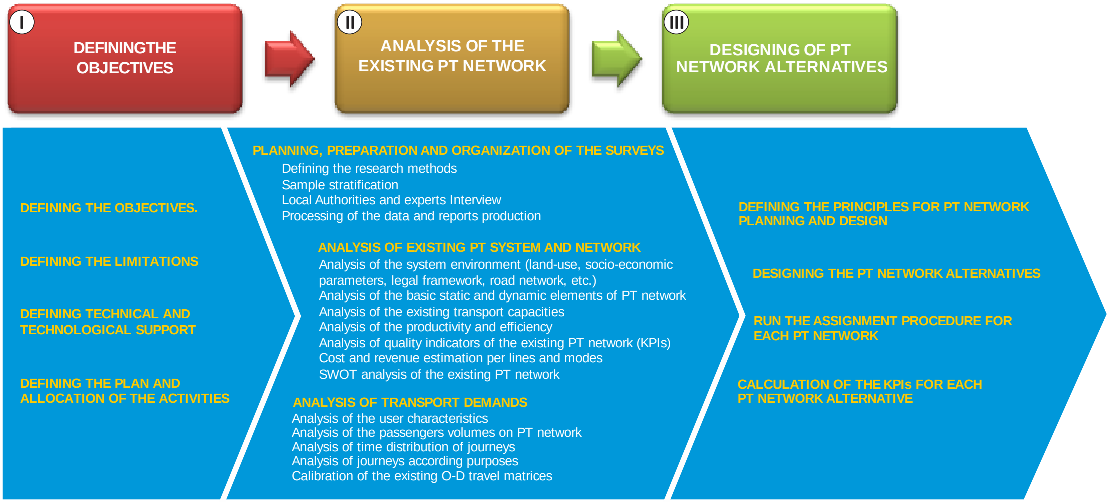


Fig. 2.
Methodology for PT network planning and design

STEP 2: The task of planning and design a PT network from scratch is rarely presented. Most cities have some form of PT system and the main challenge is to define the key strategies and tactics to improve PT network. Therefore, the second step of proposed methodology is the analysis of existing PT network and the research of transport demand. Output of this step should shed a light on improvement and re-design possibilities.

The analysis of existing PT system in the broader sense comprises also the basic elements of urban land planning, demographic and socio-economic characteristics, as well as the analysis of the existing street network. Additionally, attitude of stakeholder groups (users, local authorities, operators, experts) and transport demand are researched. This requires a wide set of different methods presented in the following table.

Table 1
The analysis of existing PT system in Belgrade – applied methods

No	Analysed element	Method	Data source
1	System environment	Desk research	General plan, Master plan, etc.
2	Historic development	Desk research	Studies, projects, expertise
3	Transport network	Desk research	N/A
4	PT system (static and dynamic elements, network KPI, costs, …)	Desk research	Data from Directorate for Public Transport City of Belgrade, Reports from electronic vehicle management system (BusPlus), etc.
5	Transport demand and users' characteristics	Survey - Passenger counting and users' interviews	N/A
6	Personal attitude of local authorities, operators and experts	Survey - Direct interview	N/A

STEP 3: Final step is the designing of the new PT network. To achieve goals set in Step 1 one must define a list of key principles for network planning and design. The more complex PT system is the more specific principles are. For PT network planning and design in Belgrade key principles defined are:

- *Plan and design PT network in alignment with land-use planning and socio-economic development.*
  Very often the requirements of PT system are neglected in planning of land-use and this is often said to be one of major pitfalls of PT systems. Integrated approach might lead to mutual benefits both for the city and its PT system.
- *Create integrated transport network to support seamless multi-destination travel while meeting the specific passenger origin-destination demands to insure reasonable number of transfer per one journey.*
  The duality in PT planning regarding tailor-based and ready-made approach is analyzed in previous chapter of this paper. We propose balanced approach: integration of all transport services to support "anywhere-to-anywhere" journeys with optimized number of transfers. It is important to always have on mind a complete PT network not a piecemeal changes of some parts of it (sections, lines, modes), i.e. system approach is crucial.
- *Retain at the greatest possible extent the existing user habits and recognizable image of the existing PT network.*
  Most cities have some form of PT system the users are familiar with. The main challenge is to define the key strategies and tactics to improve PT network while retaining its positive features.
- *Plan a hierarchy of lines into a network.*
  The basic element of PT network is the line. Clear understanding of the line and its elements is needed but not sufficient condition for achieving the "network effect". Each line must have a clearly defined role in network hierarchy. Lines should have consistent stopping patterns throughout all operating hours and reliable timetables.
- *Increase journey speed and system reliability.*
  Journey time is one of the most important factors for passengers in transport mode selection. Public transport planning should aim for travel speeds comparable to or faster than door-to-door travel times that can be achieved by car (Nielsen et al 2005; Mees 2000, 2010). Another important factor is the system reliability. Service reliability can be defined in terms of the variability of service attributes and its effects on passenger behavior and on operator performance (Abkowitz et al. 1978). Providing reliable service means keeping vehicles on schedule, maintaining uniform headways and minimizing the variance of maximum passenger loads (Levinson 1991). Importance of travel time and service reliability must be acknowledged in PT network planning and design.
- *Maximize the volume/capacity ratio - optimal network frequencies.*
  Some parts of existing PT network, usually suburban and local lines, have low frequencies making PT less attractive comparing to passenger cars. On the other hand, other network sections have so high frequencies resulting in congestion and unreliability, which may cancel the positive effects from shorten dwell times. Optimization of transport supply (frequencies and capacities) based on transport demand will result in higher utilization of resources, cost reduction and increase in overall quality of service.
- *Minimize No of terminals in the city centre – replace radial lines with a network of pendulum (diametric) lines.*
  The City of Belgrade has a problem of many PT line terminating in the city centre. There are many similar examples in other cities worldwide. Radial PT lines should be replaced with a network of pendulum (diametric) lines running between suburban centres via city centre. This will improve the efficiency of the system and quality of service for passengers while at the same time highly attractive areas in city centre are left for other use, e.g. the City of Belgrade is turning a wider central area into a pedestrian zone.
- *Coordination of convenient, fast and easy transfers.*
  Create integrated transport network to support seamless multi-destination travel results in higher transfer rate in the PT system. Fast and easy transfers support fast journeys to dispersed destinations within a public transport network (Nielsen). Therefore, this is an important element in creating high quality PT system. However, one can argue about the definition of "fast and easy transfers". Nielsen et al 2005 claim that at interchanges walking distances between services should be very short - preferably no more than 10 metres. This is very hard to achieve in real PT systems.
- *A shift to more environment friendly PT modes.*
  The positive effects on the environment which PT has comparing to cars are well known. However, some PT modes (e-bus, trams, trolleybus) are more environment friendly then others. Favoring those transport modes will have notable effects on overall quality of life in the catchment area as well as throughout the city.
- *Make the system economically sustainable.*
  The explicit request from the City of Belgrade was to reduce operating costs of PT system. This can be an important principle for the systems with limited financial resources.

Turning principles into operational actions is not always straightforward, particularly where multiple further factors enter consideration (Dodson et al 2011). Yet consistent, continuous and determined application of these principles can improve PT network functioning.

Some network design principles are opposed to the others. Therefore, this phase continues with the definition of the alternative PT networks satisfying all the principles to some extent. The level of meeting the principles is evaluated using KPIs.

Complete list of the KPIs for network analysis is given in the following table. A special emphasis is put on the volume/capacity ratio analysis and analysis of the efficiency indicators. To calculate the values of KPIs for each alternative network it is necessary to run the assignment procedure first. The assignment procedure was selected based on the potential demand analysis ("desired lines network").

Table 3
PT network KPIs

No	KPI name	Measuring unit
1	*Construction network length*	[km]
2	*Exploitation network length*	[km]
3	*Coef. of Line network overlapping (branching)*	[km/km]
4	*Coef. of Line network complexity*	[--]
5	*Coef. of Stops density*	[stops/km]
6	*Coef. of Line network availability*	[km/inhabitant]
7	*Coef. of Line network density*	[km/km^2]
8	*Line coefficient*	[km/km]
9	*Coef. of Line network adaptability*	[--]
10	*Coef. of Line network directness*	[--]
11	*Coef. of Line network utilization*	[passengers/km]
12	*Stop catchment area*	[km^2/km^2]
13	*Average stop distance*	[km]
14	*Coef. of Physical integration (number of multimodal stops)*	[stops]
15	*Coef. of Environmental friendliness*	[%]
16	*Production efficiency*	[vehiclekm/vehicle]
17	*Economic efficiency*	[RSD / RSD]
18	*Cost efficiency*	[RSD/departure]
19	*Average number of transfers*	[--]
20	*Journey speed*	[km/h]
21	*Average travel length*	[km]
22	*Gross transport work on line network*	[vehicle·km]

Analysis of such a complex PT system such as Belgrade's requires appropriate tools. Transport demand data processing is done in the *Public Transport Demand Analysis Tool – PTD,* a specialized software package designed by the authors of this paper. The entire computer-aided procedure of modelling and designing for PT system in Belgrade was done in *PTV VISUM Expert* software package, version 14.00 which comprises also modules: Timetable management, Line costing and revenue calculation, Detailed line blocking, Public transport interface package, Schematic line diagram and Passenger onboard survey and e-ticketing data. The package size is "2" which comprises 1.000 zones, 30.000 time profiles with unlimited number of links and nodes/stops.

4. Discussion and conclusions

This paper deals with the design and planning of PT network and key success factors in order to create high quality public transport services. We propose a simple three-step and easy to apply methodology, which was successfully implemented in PT system in Belgrade. Looking at the KPIs some of the main benefits of the new PT network in Belgrade are:

- ✓ Increased travel speed +**7,49 %;**
- ✓ Decreased network overlapping - **5,10 %;**
- ✓ Increased network adaptability (ration between journey time and in-vehicle time) **22,06%**;
- ✓ Increased stop chatchment area +**3,49%;**
- ✓ Increased cost efficiency +**1,7%** for the same productivity level**;**
- ✓ Decrease in operating costs **-9,38 %,**
- ✓ Modal shift to environment friendly PT modes (introduction of the two new tram lines, introduction of the first e-bus line and introduction of the second urban rail line)– Increased coefficient *of environmental friendliness* **+12,19 %.**

The lessons learned during PT network planning and designing in order to create high quality PT services are as follows:

- *The system approach is crucial* - always have on mind a complete PT network, not piecemeal changes to individual sections, lines or modes.
- *Always plan and design PT network in alignment with land-use planning and socio-economic development*. PT system is subsystem of a city, not a self living system.

- *Planning and design of PT network requires extensive involvement of all stakeholders and users* at all stages of the process. This requires various research methods for collecting their inputs.
- *Respect the existing user habits and recognizable image of the existing PT network*.
- *Plan for speed and reliability, but also for maximum productivity and cost efficiency.*
- *Optimization of all network parameters is key to success rather then max/min strategies*. This often means some kind of trade-off between opposite requests (e.g. passengers might accept additional transfer if journey speed in increased because of an increase in frequency etc.)
- *Evaluation of the effects requires a set of clearly defined KPIs*.

There are few possibilities for further research. Finding the optimal values of network parameters for specific conditions and constraints is one of the biggest challenges in front of the future PT network planners and designers. The second line of research could follow further consolidation of the KPIs, making them simpler and easier to apply. The other approach could be adjustment of the methodology to make it applicable in regional and intercity transport.
Finally, we can conclude that the success depends on high quality PT network planning and design with the users in focus. High tech is not a critical factor, although it can make this process even faster and simpler.

Acknowledgements

This paper is based on the project TR36027: "Software development and national database for strategic management and development of transportation means and infrastructure in road, rail, air and inland waterways transport using the European transport network models" which is supported by the Ministry of science and technological development of Republic of Serbia (2011-2016).
The proposed model was developed by the Authors within the project “MassTransNet: Urban public transport line network and definition of required capacities in Belgrade (ITS-1)”, which is supported by the City of Belgrade (March – July 2015).

References

Abkowitz, M.; Slavin, H.; Waksman, R.; Englisher, L.; Wilson, N. 1978. *Transit service reliability*, In: UMTA-MA-06-0049-78-1 (Ed.). USDOT Transportation Systems Center, Cambridge.

Bell, K. 2016. From squaresville to triangle town: Geometries for public transport network planning. *In Paul Burton and Heather Shearer (ed.) Proceedings of the SOAC 7 - State of Australian Cities Conference (SOAC 2015)*, Hawthorn, Victoria, Australia, 9-11 December 2015: 1-14.

Daniels, R.; Mulley, C. 2012. *Planning Public Transport Networks—The Neglected Influence of Topography*. Journal of Public Transportation 15(4): 23-41.

Dodson, J.; Mees, P.; Stone, J.; Burke, M. 2011. *The Principles of Public Transport Network Planning: A review of the emerging literature with select examples*. Urban Research Program, Issues Paper 15. Griffith University. 35 p.

International Association of Public Transport (UITP), 2011b. *Public Transport: The Smart Green Solution*. Brussels, Belgium.

Levinson, H.S. 1991. *Supervision Strategies for Improved Reliability of Bus Routes*. NCTRP Synthesis of Transit Practice 15, TRB, National Research Council, Washington, DC.

Mees, P. 2000. *A very public solution: transport in the dispersed city*. Melbourne: Melbourne University Press.

Mees, P. 2010. *Transport for suburbia: beyond the automobile age*. London: Earthscan Ltd.

Mees, P.; Stone, J.; Imran, M.; Nielsen, G. 2010. *Public transport network planning: a guide to best practice in NZ cities*. NZ Transport Agency research report 396. 72 p.

Newman, P.; Kenworthy, J. 1999. *Sustainability and Cities: Overcoming Automobile Dependence*. Washington, Island Press.

Nielsen, G.; Nelson, J.; Mulley, C.; Tegner, G.; Lind, G.; Lange, T. 2005. *Public Transport - Planning the Networks - HiTrans Best Practice Guide 2*. Stavanger, Norway, European Union Interreg III and HiTrans.

Nielsen, G.; Lange, T.; Mulley, C.; Nelson, J. 2006. Network planning and design for public transport success – and some pitfalls. Paper from *The Association for European Transport Conference*. Strasbourg, France.

Thompson, G. 1977. *Planning Considerations for Alternative Transit Route Structures*. Journal of the American Institute of Planners 43(2): 158-168.

Thompson, G.; Matoff, T. 2003. *Keeping up with the Joneses: radial vs. multidestinational transit in decentralizing region*s. Journal of the American Planning Association 69(3): 296–312.

TRB, 2015. *Public Transportation: Planning, Accessibility, and Parking, Volume 5*. Transportation Research Record: Journal of the Transportation Research Board, 2537, 184 p.

Vuchic, V. 1999. *Transportation for livable cities*. New Brunswick, NJ: Rutgers University Press.

Vuchic, V. 2005. *Urban Transit: Operations, Planning and Economics*. New Jersey, John Wiley and Sons.

MEGLIO MUOVERSI. THE SUSTAINABLE MOBILITY IN THE PROVINCE OF REGGIO CALABRIA

Domenica Catalfamo[1], Giuseppe Amante[2], Giovanna Chilà[3], Maria Rosaria Trecozzi[4]
[1,2,3,4] *Provincia of Reggio Calabria, Reggio Calabria, Italy*

Abstract: Meglio Muoversi is a projects realized by the Province of Reggio Calabria in order to realize a process of planning, integrated management and monitoring able to increase the accessibility and to produce a modal shift towards more sustainable transport modes. Two services of advanced mobility flexible in space and time have been activated with Meglio Muoversi: Chiamabus and C'Entro. Chiamabus is a dial-a-ride transport service, C'Entro is a Car-sharing service and provides for the promotion of the Car-pooling. Both services are complementary to the services existing in the territory and are complementary one each other with respect to the offer of transport. Chiamabus and C'Entro are managed by a Provincial Operating Centre making use of the most advanced technological systems for management and monitoring. Below we describe the components of Meglio Muoversi as well as the results of Chiamabus, with particular reference to the services provided between different transport nodes. Finally, we describe find the development perspectives considering both services envisaged, and potentialities of the Provincial Operating Centre that, for the way it is designed, results an open system able to host and manage further services for mobility.

Keywords: dial-a-ride transport service, car sharing, sustainability.

1. Introduction and state of the art

In the last years, sustainable mobility is the object of different strategies at international and national scale.
The General Plan for Transport and Logistics (2001) indicates, among its objectives, the satisfaction of the mobility demand by a transport supply with adequate levels of service, the realization of a safe and sustainable transport system, the efficiency of public spending and the quality of services. Among the transport policy guidelines, in addition to environmental sustainability and safety, the aim is the liberalization and privatization, to mobility in urban areas, to introduce an integrated planning process between transport and land, through intermodal and integrated networks.
As reported in the Action Plan on Urban Mobility (2009), local, regional and national authorities should be geared to the sustainable transport objectives, with a focus on the mobility needs of vulnerable users, including persons with disabilities, the elderly, subjects with economic hardships.
The White Paper - Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system (COM (2011) 144) shows the addresses to be pursued for obtain a competitive and sustainable transport system.
The Guidelines. Developing and Implementing a Sustainable Urban Mobility Plan, aimed at accelerating the widespread adoption of Sustainable Urban Mobility Plans, as provided for by the Action Plan on urban mobility.
One of sustainable mobility tools implemented in different realities as support to local public transport systems is represented by the call transport systems, also known as Demand Responsive Transport (DRT) or Dial-a-Ride services. The call transport systems generally involve the use of a fleet of vehicles of small dimensions, such as to enable the performance of displacements personalized according to user requests (with source and destination choices from time to time), carrying a number of users at a time and managing the concatenation of paths with a certain level of flexibility to be able to satisfy all the requests.
The DRT system is able to plan the route of each vehicle used according to the requests received. In general, the attempt is to minimize the operating costs that, in the case of maximum flexibility, may increase, and to maximize the level of service offered to the user, proposing the services that are consistent with the requirements. The management of these systems is supported by specific software for the planning and management of the service, GPS satellite systems for vehicle tracking, communication systems, GIS systems for spatial information management.
The activated service models could be:

- Fixed line at booking, with defined paths but ran only performed in the presence of reservations,
- The fixed-line deviations, similar to the previous, but in which small deviations in the default location are authorized,
- The model many to one, which picks up passengers at different points and leads them toward the same destination,
- The model many to many, offering complete flexibility both in origin and in destination.

Regarding the deployment of DRT systems, in Italy the first experiences are those of Imola in the 80s, which later evolve and for large urban areas of Rome, Milan, Genoa, for both small towns and mountain communities, as in services, for example: EccoBus, in the province of Alessandria; StradiBus, in Cremona; Prontobus, made in Sarzana, La Spezia; AllôBus and AllôNuit, in Aosta and the surrounding towns; Provibus and MEBUS, in the province of Turin.
Another example of mobility systems is car sharing, a system of car rent without driver. In Italy, different system of car sharing are diffused in Rome, Firenze, Milano, Torino, …

[1] Corresponding author: domenica.catalfamo@provincia.rc.it

Meglio Muoversi is a Local Integrated Development Programme realized by the Province of Reggio Calabria, thanks to a funding POR Calabria FESR 2007-2013 – Line of Intervention 8.2.1.1, approved with Resolution of the Regional Council 466/2012, concerning the Inter-municipal Mobility Systems. The objective of Meglio Muoversi is the pursuing of the sustainable mobility in its three variations of: social sustainability, economic sustainability and environmental sustainability. The first one aims at reducing the accident rate and the improvement of accessibility, the second one at efficacy and efficiency, the third one at reducing environmental impacts. In this perspective, with Meglio Muoversi we want to realize a process of planning, integrated management and monitoring, of advanced mobility services, aimed at thickening tangible and intangible networks of connection (accessibility), changing the travel behaviours of users to discourage the use of private cars and foster the integration between various modes of transport (safety and environmental impacts, efficiency and efficacy). Two services of advanced mobility flexible in space and time have been activated with Meglio Muoversi: Chiamabus and C'Entro. Chiamabus is a service on demand, C'Entro is a Car-sharing service and provides for the promotion of the Car-pooling. Both services are complementary to the services existing in the territory (e.g. road and rail Public Local Transport) and are complementary one each other with respect to the offer of transport, because they provide different services with different infrastructures, and with respect to the demand, because they aim at satisfying various categories of users.
The components of Meglio Muoversi are described here below as well as the results of Chiamabus, with particular reference to the services provided between different transport nodes. Finally, you can find the development perspectives considering both services envisaged (Chiamabus and C'Entro), and potentialities of the mobility centre that, for the way it is designed, results an open system able to host and manage further services for mobility.

2. Territorial areas and centres attracting of the Province of Reggio Calabria: the analysis of Reggio Calabria basin

The Province of Reggio Calabria is a peninsula washed by the Tyrrhenian Sea and the Ionian Sea and stretches out towards Sicily forming a bridge for links between the Europe and Sicily. The territory is characterized by presence, in the space of a few kilometers, of different environments: in particular, the hinterland is characterized by a morphological structure that is connected with the Aspromonte mountain system, while the coastline is characterized by coastal settlements which have a main development between the shoreline and the coastal roads.
A peculiar place which stands out on its own is the City of Reggio Calabria, the largest city of Calabria and the largest in terms of municipal territory (236 sq km), that is characterized by a considerable extension along the coast (over 10 km) and by a territory with altitudes ranging from sea level to over 1800 metres high. The city, which alone accounts for 70% of the population of the entire area covered by this study, is indeed predominant in relation to other nearby towns and is a real pole of attraction of mobility
Demand mobility in the Province of Reggio Calabria is related to a study area including 576,693 residents and 189,946 families; a percentage of about 47% of these moves for work or study reasons.
Beginning from data available in transport literature and from the application of demand model of transport (Cascetta, 2009), we have estimated the transport demand on a provincial scale in a generic day, for the following reasons:

- Home-work (CL),
- Home-school (CS),
- Home-personal services (CA).

Main results are reported in Catalfamo, Amante, Chilà (2014).
Inland areas of the Province are characterized by low accessibility in terms of infrastructures and services: the privately owned car represents the only modal alternative, especially for specific groups of citizens and in the peak-off time period.
The high percentage of those who use their own private car produces very low levels of environmental quality and energy efficiency, a low level of both accessibility and attractiveness of areas.
Accessibility has always been a decisive factor in economic development: improving accessibility allows a change of economic activities, increasing the economic surplus and the levels of local employment.
The aim of this work is to implement a flexible transport service in order to improve the accessibility of the specific area of the Province of Reggio Calabria and to promote a modal shift towards more sustainable alternative transport.
In order to optimize the transport service on demand provided for within the CHI-AMA BUS operation, the provincial territory has been divided into mobility territorial areas, by identifying centres attracting the service as main destinations of the connections to be activated, classified as:

- Local attracting centres, defined for every territorial area,
- Provincial attracting centres, valid for the whole Province.

As regards the local attracting centres, they are defined according to territorial area, representing the main destination of movements and, therefore, of the connections to be activated with CHI-AMA Bus (mainly but not exclusively many-to-one service). The division of the Province into territorial areas was carried out starting from the analysis of the demand of mobility, in order to maximize, within each area, according to the canonical definition of study area (Cascetta,2009) the effects of the interventions planned, considering transport and socio-economic elements.

The study has led to an organization of the service based on 8 mobility territorial areas, identified by the Municipality, that within the area, represents the main destination of movements and that, therefore, is classified as local attracting centre (Table 1).

Table 1
Territorial areas

Territorial Area	Municipalities
Reggio Calabria	Reggio Calabria, Calanna, Campo Calabro, Fiumara, Villa San Giovanni, Laganadi, San Roberto, Sant'Alessio in Aspromonte, Santo Stefano in Aspromonte, Motta San Giovanni, Cardeto
Melito di Porto Salvo	Bova Marina, Brancaleone, Condofuri, Palizzi, Africo, Bagaladi, Bova, Roccaforte del Greco, Roghudi, San Lorenzo, Staiti, Melito Porto Salvo, Montebello Ionico
Bovalino	Ardore, Benestare, Bianco, Bovalino, Bruzzano Zeffirio, Caraffa del Bianco, Casignana, Ferruzzano, Sant'Agata del Bianco, Careri, Platì, Samo, San Luca
Locri	Locri, Portigliola, Sant'Ilario dello Ionio, Siderno, Agnana Calabra, Antonimina, Canolo, Ciminà, Gerace, Mammola
Roccella Ionica	Caulonia, Gioiosa Ionica, Grotteria, Marina di Gioiosa Ionica, Martone, Roccella Ionica, San Giovanni di Gerace, Camini, Monasterace, Riace, Stignano, Stilo, Bivongi, Pazzano , Placanica
Gioia Tauro	Gioia Tauro, Rizziconi, Rosarno, San Ferdinando, Molochio, Oppido Mamertina, Taurianova, Terranova Sappo Minulio, Varapodio
Polistena	Anoia, Candidoni, Cinquefrondi, Cittanova, Feroleto della Chiesa, Galatro, Giffone, Laureana di Borrello, Maropati, Melicucco, Polistena, San Giorgio Morgeto, San Pietro di Caridà, Serrata
Palmi	Bagnara Calabra, Palmi, Scilla, Seminara, Cosoleto, Delianuova, Melicuccà, San Procopio, Santa Cristina d'Aspromonte, Sant'Eufemia d'Aspromonte, Scido, Sinopoli

The local attracting centres identified for every territorial area are: Reggio Calabria (to be considered in terms of conurbation system Reggio Calabria - Villa San Giovanni); Palmi; Gioia Tauro (to be considered in terms of conurbation system Gioia Tauro – Rosarno); Polistena; Roccella Ionica, Locri (to be considered in terms of conurbation system Locri – Siderno); Bovalino; Melito di Porto Salvo.
In every local attracting centre, the service is supported, as provided for by the project, by the installation of infotainment stands performing the double function of information to users and booking service.
As regards the provincial attracting centres of movements, to be considered valid for every territorial area, the preferential destination of the connections activated, are listed below:

- Tito Minniti Airport of Reggio Calabria,
- Ports of Reggio Calabria and Villa San Giovanni,
- Main railway stations,
- Hospitals and Hospital facilities,
- Provincial healthcare facilities,
- Universities,
- Provincial administrative and judicial centres.

3. The Chi-Ama Bus service: management and exercise data

The transport services on demand and car-sharing services are managed by a mobility centre making use of the most advanced technological systems for management and monitoring. The Provincial Operating Centre is described in the below.

3.1. Provincial Operating Centre

The transport services on demand and car-sharing services are managed by a mobility centre making use of the most advanced technological systems for management and monitoring. The mobility centre rules the relationships with the users for reception and management of bookings, the relationships with the operators of Chiamabus to transfer the bookings, the relationships with the on-board devices of the cars of C'Entro to authorize withdrawal and delivery.
The Operating centre comprises two main units: Earth system and Transmission system.
The earth system is the functional block at the Operating centre including all the functionalities necessary to provide the bus service on demand and car-sharing service. There are both back-end functionalities, namely concerning the computational part and data processing to provide the service, and front-end functionalities, or rather the service provided to the user and necessary to accede to and use the service.

The back-end processes include all those macro-services, defined as modules, designed to collect real-time the requests of the users (booking request, changes, users' registration) and data coming from in-service means. The earth system shall process the collection paths and the service planning, both planned and real-time, after the requests of the users. This part includes also all those functionalities that need data from vehicles with the purposes to control and monitor the service. The earth system comprises the parts described in brief here below.

- System Engine, the infrastructure of the operating centre, designated to manage the support functionalities, aimed at guaranteeing the functionality of the services provided. It guarantees the real-time data acquisition and their filing,
- Management and filing of OBD data (On Board Data) arising from the OBU workstations of vehicles, through a network manager system, representing the control tool which supports the rest of the processes of the platform CHI-AMA bus to provide the services,
- GIS, the component engaged in managing every service linked to the georeferencing, first of all, those designated to display real-time the positions of the means, to display the road graph and points of interest. The component GIS provides for the implementation of a specific Geospatial architecture based on GeoServer, an open source server for the interoperable management of geospatial data, and a monitoring system of vehicles, based on the information collected by the devices of Exercise Data Transmission System installed in the vehicles,
- Booking Form, functional block used by the user to require the use of the service (booking, information request, changes etc.) and to check the status of his/her booking and of the means. This form includes: Account System e Profiling; Charging Form; Payment Form,
- Fleet Management, engaged in managing the fleets of means designated to provide the service, includes all important data concerning means, drivers and planning of rides. It is the management component allowing the integration and planned management of fleets,
- Report management, allowing to generate appropriate final reports on the use of the system (such as show, for every vehicle, the kilometres made, the frequency of use, the number of users served etc.). The form allows to carry out specific analyses concerning the assessment of indicators of service, and more in general a series of analyses carried out on the basis of keys and filters selected by the operators,
- Interaction channels.

The platform CHI-AMA Bus allows the user making use of the services provided through the use of the following interaction channels: Web portal; Mobile Application; Call centre, interactive Infotainment Stands.
The modular services of fleet management, GIS, report management, payment for the transport service on demand shall be also functional to the implementation of the car-sharing service.
In particular, through the Operating centre it will be possible: register users and fill in on-line the subscription forms; manage bookings; accede via web, PC, tablet, smartphone, other devices and via mobile Apps; manage the payments, according to different forms of charging, and invoicing; manage the opening of doors and start of the engine; manage the maintenance of the fleet; monitor the range of diesel and electric vehicles of the fleet; receive and store data concerning the positioning of the Car Sharing fleet, coming from the OBU, dedicated to the Car Sharing, through interfacing with the data reception system of positioning of the Car Sharing system (therefore not through direct interfacing with the OBUs); display on the GIS component data concerning the positioning of the Car Sharing fleet and the status of the means; extend the use of the Fleet Management system also to the means of the Car Sharing fleet, with concurrent allocation of the OBU; manage the reallocation of vehicles depending on bookings; carry out the report management of data concerning the use of Car Sharing means; expose data of report management through web services; have accounts available with appropriate profiling.

3. 2. Exercise data for Chi-Ama Bus

Chiamabus, active as of 20th July 2015, is executed by private operators, having subscribed a Framework Agreement through public procurement, with means having a variable capacity from 8 to 50 seats. The service mainly collects requests in urban and metropolitan areas, but performs also services with origin and destinations in the rest of Italy. At the moment there are 5 transport operators:

- Operator 1, with headquarters in Reggio Calabria operating with a 8-seat vehicle (excluding the driver),
- Operator 2, with headquarters in Villa San Giovanni, operating with a 8-seat vehicle (excluding the driver) and a 50-seat bus, and that, compared to the fleet of the Province of Reggio Calabria, has also made available: a further 8-seat vehicle, a 25-seat bus, a 35-seat bus, a 50-seat bus,
- Operator 3, with headquarters in Stilo, operating with a 7-seat vehicle + 1 seat for disabled person (excluding the driver),
- Operator 4, with headquarters in Reggio Calabria, operating with a 8-seat vehicle (excluding the driver).

As of 26th October it represents an effective service in support of the integration between both banks of the Area of the Strait to improve the connections having as origin and destination the Airport of Reggio Calabria. Several requests are

registered everyday by passengers from Messina using Chiamabus that coincide with every arriving and departing flight.
With reference to the last available data, we refer here below a comparative table of the main indicators detected on 31th July 2016 (Table 2). According to this data (July, 31, 2016), about 16.000 passengers have been users of Chi-Ama Bus, of which 57 % with 8-seat vehicles. A percentage about 90% of total of transport services have been realized with 8 seats-vehicles, with a 3,5 pax for travel and a rate of occupancy about 0,44. In effect, Chi-Ama bus allow to satisfy weak demand, during off – peak hours, as support of the local public transport. In relation to aggregate data concerning the travels carried out to and from the Tito Minniti airport of Reggio Calabria, we highlight that they represent in the aggregate almost 70% of the Chi-Ama Bus services.
Other attracting centres are the healthcare facilities part of the national healthcare service, schools of all levels and Universities, and the tourist resort of Gambarie, privileged destination during the plentiful snowfalls of January.

Table 2
Aggregate exercise data

Indicator	Value
Tot. no. of travels	2.864
Tot no. of travels – 8 seats	2.616
Tot no. of travels –> 8 seats	248
Tot no. of passengers carried	15.903
Tot. no. of passengers carried – 8 seats	9.128
8-seat vehicle average occupancy rate	0,44
Tot. no. of passengers carried –> 8 seats	6.775
Tot. no. Km made	91.240
Pass./km	0,17
No. travels with O Tito Minniti Airport	800
No. travels with D Tito Minniti Airport	950
No. Travels With O or D Tito Minniti Airport	1.750
% travels with O or D Tito Minniti Airport	61%
Tot. no. of passengers carried towards Tito Minniti Airport	2.540
Tot. no. of passengers carried from Tito Minniti Airport	2.624
Tot. no. of passengers carried towards or from Tito Minniti Airport	5.164
No. travels with O a transport node	1.893
No. travels with D a transport node	1.152
No. travels with O and D a transport node	1.116
No. travels with O or D a transport node	1.929
% of travels with O or D a transport node	67%
No. of passengers carried towards O a transport node	5.767
No. of passengers carried from D a transport node	3.165

Table 3 shows synthetic data service Chi-Ama Bus on the first year of service activation, and MEBUS, in the area called service Turin metro, for 2013, the first year from which data are made available and useful for the comparison. The MEBUS is a DRT service that is activated by reservation. To use it, a telephone reservation toll on the area of interest, indicating the day and time in which the service is used, the source and destination. The service was set up for the first time in April 2008 in the North East area and expanded later to North West Basin, the South West Basin and the Hill Chierese. Data show that Chi-Ama bus is characterized by a more higher value for the parameter *Number of pax/travel*; the other parameters are similar.

Table 3
Comparison between Chi-Ama Bus and MeBus

Indicator	MeBus (2013)	Chi-Ama Bus (July 2015 – July 2016)
Tot. no. of passengers carried	15.000	15.900
Tot. no. Km made	104.000	91.000
Tot no. of travels	11.000	2.864
No. pax/travel (average value)	1,4	5,5

3. 3. C'Entro

C'Entro is the Car Sharing service, the activation of which is scheduled for next autumn, it will be completed with 18 diesel cars and three electric cars that can be rented in 5 municipalities of the province: Reggio C., Villa SG, Joy T ., Locri and Siderno. Have been reserved 40 stalls at the main pole attractors (transportation hubs, hospitals, etc.,), and were reserved another 12 stalls further 6 municipalities to ensure the break during the rental in highly attractive areas.

4. Conclusions

For a better efficiency and efficacy of the service, the subscription of a higher number of operators is desirable, with more headquarters spread in the provincial territory: the objective is the creation of a denser network of tangible and intangible connections, allowing to optimize the services in the urban centres, and, concurrently, the creation of valid and sustainable modal alternatives in the most interior and less accessible areas of the Province of Reggio Calabria.

Acknowledgements

Meglio Muoversi is a projects realized by the Province of Reggio Calabria thanks to a funding POR Calabria FESR 2007-2013 within Local Integrated Development Programmes.

References

Cascetta, E. 2009. *Transportation Systems Analysis. Model and Application*, Springer, New York, U.S.A.

Catalfamo, D.; Amante, G.; Chilà, G. 2014. Dial–a–ride transport service of the Province of Reggio Calabria: Chi-Ama Bus. In *Proceedings of the International Conference on Traffic and Transport Engineering.*

The General Plan for Transport and Logistics 2001. *Piano Generale dei Trasporti e della Logistica* 2001. DPR 14 marzo 2001, Ministero dei Trasporti e della Navigazione, Roma, Italy.

European Commission 2007. *Sustainable Urban Transport Plans, Preparatory Document in relation to the follow-up of the Thematic Strategy on the Urban Environment*, European Commission, Brussels, Belgium.

European Commission 2009. *Action Plan on Urban Mobility*. *COM(2009)490/5,* European Commission, Brussels, Belgium.

European Commission 2011. *Libro Bianco. Tabella di marcia verso uno spazio unico europeo dei trasporti - Per una politica dei trasporti competitiva e sostenibile*. COM(2011) 144 definitivo, European Commission, Brussels, Belgium.

Wefering, F.; Rupprecht, S.; Bührmann, S.; Böhler-Baedeker, S. 2014. Guidelines. Developing and Implementing a Sustainable Urban Mobility Plan. Prodotto per la Commissione Europea. Available from Internet: <http://www.eltis.org/sites/eltis/files/guidelines-developing-and-implementing-a-sump_final_web_jan2014b.pdf.>.

EVALUATING COSTS AND BENEFITS OF POSSIBILITIES OF MODAL SPLIT CHANGE - EXAMPLE OF BASIC TRIP GENERATOR

Milos Pavlovic[1]
[1] *Highway Institute, Belgrade, Serbia*

Abstract: Shops and markets in modern life represent a significant generator of travel, whereby contribute to the temporal, spatial distribution and modal split travel. This paperwork is focused on research, evaluating the benefits and costs based on a comparison modal split distributions and trips that are aimed at going into a hyper market. The study was done during the weekend in the city of Pozarevac, and as a research subject was shop - hyper market on the periphery of town. Basically, that are indicators that describe the costs and benefits incurred during a single trip. Such a simple example shows the possible savings based on the selection of the mode of transport when going to purchase, in accordance with the consumer basket, i.e. the size of the average purchase price, weight of purchased goods, the distance traveled, and travel time. We are witnesses of today that the sources attractions such as hypermarkets, primarily generate passenger travel made by car. The intention of the author in this paperwork is to point out the current modal split distribution and the possibilities of future traffic; accelerate, motivate and popularize the development of other modes of transport in accordance with the basic principles of sustainable mobility, especially when it comes to developing countries. Prediction and prevention in such cases can significantly affect the future development of transport infrastructure. Thus, changing the mode of transport, possible multiplied savings needs to justify and change the awareness of today's stagnant local society. Multicriteria evaluation of the effects of a basic trip regarded through the economic, health, social and other benefits may change the current modal split travel. The strategic approach observed through acts, legislation and principles and implemented through a significant number of programs (discounts, benefits, etc.) must have unequivocal support of the authorities and the local community, in order to progress towards sustainable development.

Keywords: cost and benefits, evaluating urban transport, modal split, sustainable transport, spatial and transport planning.

1. Introduction – Sustainable Progress

Transition towns and technological development of urban areas modify the existing environment and urban area, thereby leaving a mark on people and the environment. Steady progress has generated a number of factors pushing the burden on residents, also mixing them in quality of life. Experience are valuable heritage, which can be of invaluable importance to the proper application. The practice in urban planning takes into account the integration, participatory, and evaluation principles to satisfy current and future needs of urban residents for mobility, and to ensure a better quality of life in cities and their surroundings. Sustainable Urban Mobility Plan is to create a sustainable transport system means ensuring the availability of jobs and services to all, improve safety and security, reduce pollution, greenhouse gas emissions and energy consumption, increase efficiency and effectiveness in the transport of people and goods, the scaling up of attractiveness and the quality of the urban environment. It is important to develop a common understanding among key stakeholders of what sustainability and sustainable mobility means for a city and its surroundings. In development of sustainable mobility, with transport and mobility should take into account social, economic and political-institutional criteria. The plan should be based on a long-term vision for the development of transport and mobility for the entire city agglomeration, both at macro and micro level.

A set of different measures in all urban structural units create conditions for improving the street scene, the natural environment and living environment.

One of the applied measures found a foothold in the modal split as one of the most important factors and parameters of the quality of community life and urban sustainability. The chance is reflected in the application of international experience and the rate of custom attributes and characteristics of the local community.

2. Environment

Pozarevac is a city with about 70,000 residents. Transportation network of the city burden for our conditions a large number of vehicles (a high degree of motorization in the city and municipality of about 1: 5). It stipulates that during the day citywide found in the dynamic and stationary traffic around 9,000 domicile vehicles, with about 7,000 base state roads I and II, and about 4,000 of the catchment area (municipality - city). This points to the city during the day there are around 20,000 vehicles, the stationary, as in the dynamic state. Almost 50% of these vehicles burdens of the city center.

3. Research – basic trip generator

This feature provides a summary of a study trip generation prepared for a major hyper market company by looking at traffic conditions related to shopping and buying.

The study was done during the weekend and city of Pozarevac, and as a research subject was shop - hyper market on the periphery of town. Number of visitors, buyers that use a hyper market as main source of supply and use different

[1] Corresponding author: milosapavlovic@gmail.com

ways of transportation to get to the desired destination. Today, hyper markets represent a significant generator of travel. They contribute to the temporal, spatial distribution and modal split travel.

Fig. 1.
Hypermarket location
Source: (www.google.com/earth)

It is important to note that there is parking in front of the hypermarket. Parking lots, are not marked on the asphalt, but regardless of this, capacity of parking amount are approximately 60 cars.
As mentioned earlier, the study was done during the weekend days. During the study 600 people were interviewed during the both days. During the study it was registered that weekend days have peak hours between 11-14 am and 15-19 pm. Sample has been taken from both, from 150 morning and 150 afternoon from peak hours, so it could be analyzed distribution timeline.
selection of the modal split, way of transportation has important role in every day life of average person.
Analyze of data collected from parking, shown us that unique average time spent on parking lot amount 1 hour and 12 minutes. Following an examining the arrivals of people at hyper market, it was found that 98.2% of people arrive by a passenger car, 0.4% came by bus and a 0.3% by taxi, and 1.1% by some other mode of transportation (bicycle, walking, etc.).
One of the main questions in the survey was about frequency of visiting a hyper market, where 88.6% of the respondents said that they go to hyper weekend market at 7.2% said that they go to hyper market at weekend and work day and 4.2% said that they only work at the moment.
62.8% of the respondents said that go to the weekly supply shopping at the hyper market (every week - 4 times at month), 23.9% two or three times during the month, 12.1% in one month time, 1.2% - have answered other frequency departures.
Cities to develop their transport networks, thus modal split as inseparable components of expressed needs and demands of a quality living environment, habitat, often cultural and historical heritage - heritage is one of the main causes of the problem. Like most cities around the world, so the city of Pozarevac outlines of its network was in earlier periods, which to this day remain unchanged. City as a unit of the demographic characteristics of the one nation, certainly shares the fate of their country. General known historical events during the previous period and the current economic situation. Development and technological progress is hampered by the disabled during the previous decades. Purchase and finance of the company is at a low level, leaving the consequences and the degree of motorization also reflecting on the functioning of all the city's structural whole, including the modal split.
Average travel distance that exceed customers is 4.1km while average travel time 19.2min amount.
Consumer basket has a crucial role in the life of the average man. This applies particularly to the developing countries. The survey also included a questions about average amount of purchases that take place in the market. They are divided into categories according to the amount of money:

1. Less than 5000 dinars,
2. From 5000-10000 dinars,
3. From 10000-25000 dinars,
4. Over 25000 dinars.

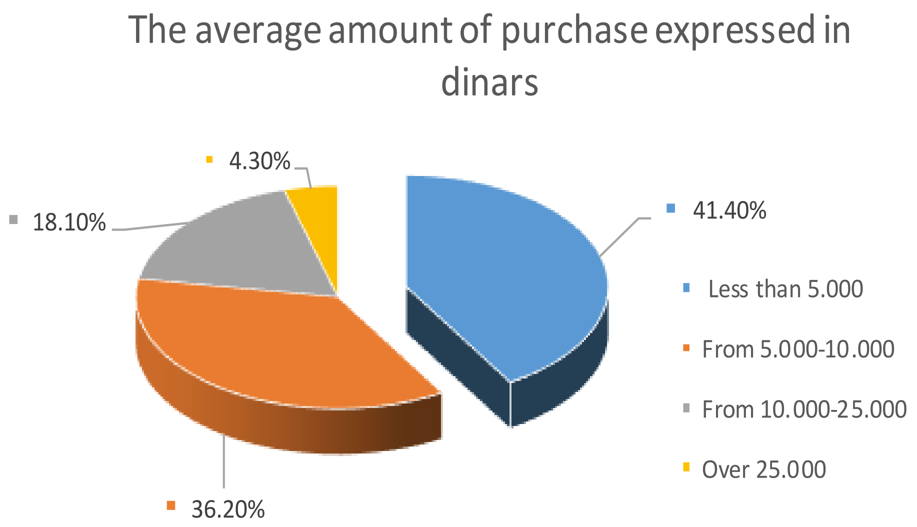


Fig. 2.
The average amount of purchase - dinars
Source: (Author)

Average purchases during the investigation amounted to 12,369.00 dinars. If we consider distribution, 4.3% of consumers belonging to the group of four, 18.1% belongs to a group of three. Only 36.2% of consumers can afford sums of category 2, while the largest part belongs to group one. These results speak volumes about the purchasing power of the population. Why is such a synthesis is made? Just to highlight the weak purchasing power and determine the appropriate measures that would create a different distribution, and as a result we have a different modal split. It should not be forgotten that the arrival of the passenger car market entails fuel consumption, as well.
Also, research included weight of the goods purchased, where customers were asked to measure the weight of their goods on a digital scale. Similarly as in the previous case, the results were divided into categories:
CTM theory, first two types of traffic flow transmission between cells can be used in lane blockage analysis. These two types can be classified as given below (Gomes and Horowitz, 2006; Gomes et al., 2008; Dong et al., 2012):

- Less than 3 kg,
- From 3 - 5 kg,
- 5 - 10 kg,
- Over 10 kg.

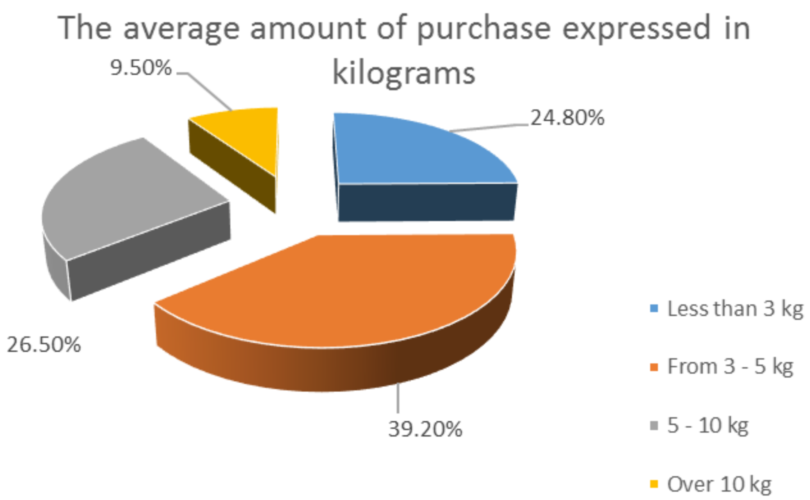


Fig. 3.
The average amount of purchase - kilograms
Source: (Author)

Most individual purchases had a weight of 3 - 5 kg (39.2%), followed by (26.5%) of 5 - 10 kg. The weight of the goods purchased less than 3 kg 24.8%, while over 10 kg bought only 9.5% of customers. By analyzing this data the information is that more than 60% of customers can switch to a different mode of transportation, and points to the fact that passenger car is not necessary.

4. Policy and measures for motivating modal split

Significant contribution to changing preset picture off modal split distribution and spatial distribution can also be made from many different views. Target group of citizens could be always detected, the largest individuals in today's society - the average citizen who lives on the edge of existence. Quality designed strategies and programs could modify the everyday life of residents of the city, thereby influencing the behavior and habits of people. What we can definitely feel in everyday life is that it is necessary to make a remarkable number of decisions. Decisions taken at a given moment are caused by a number of factors, in order to make the best one. Economy, finance and money today play an important role in the life of man, often existential. Accordingly man during life is often driven by economic motives administration. Often giving a discount, as well as the introduction of fees for certain things can significantly affect the outcome of making decisions and exercising other choices in all aspects of life of one individual. In the same way, can influence the purchasing decision in a particular place, the amount of purchase, mode of arrival and departure, and the initial and final point of the trip. Measures to be taken in order to achieve the desired result may not always be a criminal-related. Increasingly, his execution around the world are experiencing a variety of programs aimed at encouragement and motivation of certain forms of behavior, through subsidies, rebates and other allowances. Why? The answer lies in the opportunity to position themselves well on the available market male incentives can provide greater benefits - both sides, but the implementation of penal policy. An example given is an experiment that was conducted during this study. Specifically, during the survey, respondents were asked questions related to potential policy benefits that supermarket could implement in the future, or the questions that refer to the close link grant discounts in relation to the choice of means of transport which carried purpose of the trip - shopping. Thus, the program would address the following: a discount on the purchase amount would be given to all who come by bike to super market, or those who choose to instead passenger car, do the shopping by bicycle. The results show the following:
For discount of 5% on the amount of the purchase price, 19.4% of which amount would agree to change the mode of transport, and it would have happened by bicycle. Discount of 5-10% results in a group of 33.7% which makes subjects who came by bicycle. 15% discount to attract 42.1% of what is already. This percentage represents a significant number of people who are ready to change habits, motivated by financial objectives. Discount of 15% generally speaking not from excessive savings. However, this is an indication of the difficult economic and social situation of society. The result obtained is not a surprise when it comes to developing countries, especially the smaller communities within the same, where the amount is less consumer basket. Otherwise, the implementation of such a program would be implemented through the registration and obtaining the numbers in the parking lot for bicycles, with the help of which they can at the ticket offices exercise the right to a discount. We should not forget that in addition to savings in the purchase of the achievement of the right to a discount, additional savings would be achieved in fuel consumption, given the choice of a new means of transport.

5. Hidden Benefits

5.1. Parking space

Compared to cars, cyclists need a little room to move, maneuvering and parking. Busy area viewed through stationary traffic leads to permanent seizure and usurpation of available space, which can be measured and compared. Average parking place for cars, can be replaced with a 7-9 cycling city. Construction of standard parking spaces for cars costing between 4,000 - 8,000 €, and the construction of covered places, or in the underground garage will cost about 16,000 €. Compared with these facts, the construction of a standard parking surface on which can accommodate 8-10 bikes cost about 1,000 € (von Harten and Sorof, 2012).

5.2. Health benefits

The benefits can be quantified and in terms of human health. Regular physical activity contributes to health and improving the quality of life of all people. The World Health Organization recommends at least 150 minutes of cardiovascular exercise during the day, such as. walking or riding a bike, in addition to strength training. According to the same alleged use of bicycles as a mode of transport, can be compared with the daily intense training of 150 minutes during the entire week (Cavill and Kahlmeier, 2008). The benefits in the cardiovascular system are achieved with a 10-minute drive away. The benefits that are associated with the use of bicycles include personal (personal) is used, then uses the community as well as social benefits. Consequences of physical activity are manifested through:

- Reducing the risk of cardiovascular disease and diabetes,
- Reduces the risk of many types of cancer,
- Reduces the number of affected by asthma,
- Control and reduction of body weight,
- Improves mood and mental health,
- Reduces the cost of health care,
- Reduces the risk of stroke and premature death.

Over the last decade, there is major recognition of the impact of the election mode of transport on health. Many of these impacts are directly related to public health expenditures; as well as the loss of productivity in the course of the disease and the inability to operate. If the health of the population can be improved through increasing non-motorized modes of transport, personal, private and public - state costs can be reduced. The study, which investigated 2,400 adults showed that those who used the bicycle as a means of transport to work were leaner, were in a better mood, they had better triglyceride levels, blood pressure and insulin levels, as opposed to those who have used "passive "carriage, respectively for transport by car.
Also, another interesting benefit of using a bicycle that appeared in recent years is that with growing popularity and increasing security. The study of accidents at an intersection, or crash of 2004, considering the account of traffic accidents involving cyclists, shows that the greater the number of cyclists who appears on an individual junction, the risk of an accident, or impact by a motor vehicle, is often lower at intersections where cyclists higher, even if such intersections recorded a higher number of accidents or collisions.

5.3. Environmental Benefits

Cycling does not use fossil fuels and is a means of transport that absolutely does not pollute the environment. Bicycles lessen the need for production, service, maintenance, and finally removing the cars.
The daily ride from 10 km saves about 1500 kg pollutant emissions of greenhouse gases annually. This applies particularly to weather losses and delays in traffic flows, where the vehicle during standstill in major European cities emit 10-13 million tons of harmful emissions annually. Increased bicycle use, especially during peak hours, will contribute to further reduction of emissions and pollutants, as well as improving traffic flow.

6. Conclusion

Recent socio-economic and cultural trends show a high level of requests for communities adapted to pedestrians and cyclists. However, a large number of towns in the absence of adequate infrastructure for safe walking and cycling. Creating a friendly community to non-motorized traffic starts building environments: connecting destinations close to each other, such as schools, parks, adequate public facilities, etc. while allowing the possibility of joint use space and land use, then the construction of buildings intended for transit, commercial implementation districts where access is enabled and adapted to cyclists, pedestrians and people with disabilities.
The compound of the planned land use and transport - traffic planning is crucial for the safe and efficient adjustment of different travel modes of transport, such as cycling and walking. Studies have shown that the infrastructure and facilities such as separate bike paths, priority at intersections, sidewalks and benches closely linked to security and active travel. Through the design and redesign and reconstruction of the environment and the environment, in order to make walking and cycling more pleasant, planners and engineers can help assist people of all ages to get the exercise they need to live longer and healthier lives. Construction of a new road could cost tens of millions of euros, as opposed to the many walking and cycling infrastructure projects, which have extremely low investment cost. Although the case of the city shows that the majority of indirect benefit is not quantifiable primarily due to lack of appropriate data bases, however, are noticeable signs of the first moves towards change and betterment for cycling flows. Unified Infrastructure guidelines in this document are aimed at encouraging and improving construction environment adapted primarily to non-motorized traffic flows - cyclists and pedestrians.

References

Cavill, N.; Kahlmeier, S.; Rutter, H.; Racioppi, F.; Oja, P. 2008. Economic analyses of transport infrastructure and policies including health effects related to cycling and walking: A systematic review, *Transport Policy*, 15(5): 291-304.
Flusche, D.; 2009. Bicycling Means Business: The Economic Benefits of Bicycle Infrastructure, Advocacy Advance-a partnership of the League of American Bicyclists and the Alliance for Biking & Walking. Available from Internet: < http://www.advocacyadvance.org>.
Pavlovic, M. 2012. *Traffic management in central zone of Pozarevac*, Faculty of Transport and Traffic Engineering, Belgrade, Belgrade, Serbia.
Belter, T.; Von Harten, M.; Sorof, S. 2012, *Costs and benefits of cycling*, Sustra MM, Ennercite, Dresden, Germany.
Pein, W. 2008, *Evaluation of On-Street Bicycle Facilities Added to Existing Roadways*, Center for Transportation Research at The University of Texas at Austin, U.S.A.

COMBINED EXPERT, STAKEHOLDER AND CITIZEN INVOLVEMENT FOR PRIORITY SETTING OF CYCLING MOBILITY STRATEGIES USING ANALYTIC HIERARCHY PROCESS

Michela Le Pira[1], Giuseppe Inturri[2], Matteo Ignaccolo[3]

[1] *University of Roma Tre, Roma, Italy*
[2,3] *University of Catania, Catania, Italy*

Abstract: Transport planning is not a simple task, in particular at the urban scale, because it implies decisions that (1) affect stakeholders with conflicting interests and (2) needs to be evaluated considering different criteria. Involving stakeholders and citizens in the decision-making process is a necessary condition for reaching consensus, while guarantying transparency and pursuing sustainability. The use of sound Multi-Criteria Decision-Making (MCDM) methods can support the decision-making process characterized by multiple criteria and multiple points of view. This paper presents an approach based on the MCDM method called Analytic Hierarchy Process (AHP) to support a public participated planning process where experts, stakeholders and citizens were involved in setting the priorities for cycling mobility in an urban context. AHP hierarchy was built by a panel of experts and stakeholders engaged in an evaluation process where their opinions' convergence was facilitated by the Delphi method. A simplified online questionnaire based on the AHP hierarchy was used to involve the general public by eliciting their preferences. The ranking of alternatives derived from citizens was significantly different from the one derived from the panel, showing that they have diverse views about the priorities for cycling mobility. A small test sample represented by students was also asked to answer to both questionnaires (AHP and simplified) to investigate the robustness of their judgments and see if there are any differences in the results obtained. The collective ranking obtained with the simplified questionnaire is more in line with individual preferences, suggesting that a simpler, easier to understand questionnaire is to be preferred when a non-expert audience is involved. In conclusion, a tailored approach is needed to elicit experts, stakeholders and citizens' preferences, while using solid decision-support methods. The proposed AHP-based approach proves to be a useful tool for decision-makers and planners to support them when dealing with public decisions affecting multiple stakeholders and to guide them in planning effective participation process.

Keywords: participatory transport planning, multi-criteria decision-making methods, consensus building.

1. Introduction

Transport systems are regarded as complex systems that include multiple agents making decision and where some characteristics emerge from the aggregation of individual behaviors (Ettema, 2015).
In this context, transport planning is not a simple task, in particular at the urban scale, because it involves decisions that affect multiple actors with conflicting interests, such as the users of the transport systems, the citizens, the transport operators, and all those who have an interest or hold a stake in that particular decision: the so called "stakeholders". If they are not properly involved since the early stages of the decision-making process, this can cause protests and even the plan failures, wasting money and time.
Nowadays it is widely recognized the importance of involving citizens and stakeholders in a participatory planning process with different levels of growing involvement (Wefering et al., 2014; Cascetta et al., 2015). The participatory approach helps to have better decisions supported by the public and to increase the transparency of the whole process, but still we are far from a comprehensive knowledge of effective participation techniques and procedures and from a satisfactory inclusion of them in the transport planning process as well.
Identifying all the relevant stakeholders and decision context plays a fundamental role in understanding who to involve, therefore a good knowledge of it is required.
Stakeholders can be represented in a pyramid according to the level of competence and public interest: the "experts" (key informants), with high competence but low stake, the "stakeholders" in strict sense (e.g. institutions, groups, environmental associations, transport companies), with competence and high stake, and the "citizens", with low competence but that act in the public interest (Le Pira et al., 2016a). The decision-maker(s) is bounded with them and should take into consideration all the different points of view.
Many guidelines describing techniques for stakeholder involvement are available in literature (e.g. Wilcox, 1994; Rowe and Frewer, 2000; Kelly et al., 2004). They can be based on vis-à-vis meetings, interviews, focus groups, but there also online engagement tools (Rucker et al., 2014).
Among the variety of available methods, those that focus on the convergence of opinions among stakeholders through interaction and communication (e.g. consensus conferences, deliberative polls), even if "anonymous" and "asynchronous" as in the Delphi method (Dalkey and Helmer, 1963), deserve a particular attention. In fact, it has been demonstrated through a variety of qualitative and quantitative methods that interaction and deliberation can change stakeholders' mind about public policy problems (Quick et al., 2015). Besides, there is also a learning effect due to interaction and participation, since participants have increased their knowledge and understanding of problems at the end of the process (Franceschini and Marletto, 2015).

[1] Corresponding author: michela.lepira@uniroma3.it

Whatever the approach used, participation experiences should be supported by the results of models and simulations that can help to plan and design them. In this respect, agent-based models can be used to reproduce the opinion dynamics on stakeholders' networks considering different type of interactions and relationship among them (Le Pira et al., 2015; 2016a).
Besides, complex decision-making in transport planning, when multiple criteria and multiple stakeholders are involved, can benefit from the use of adequate decision-support methods and procedures, such as Multi-Criteria Decision-Making (MCDM) methods. Analytic Hierarchy Process (AHP) by Saaty (1980) is a well consolidated technique to structure a multi-criteria decision-making process into a tree decision including a general goal, a set of specific objectives, evaluation criteria (and possible sub-criteria) and to finally select the best alternatives to achieve the general goal. Though AHP is generally used to elicit the choice of a single decision-maker, it can be extended to group decision-making.
Based on this premise, in this paper we propose an AHP-based procedure to support experts, stakeholders and citizens' involvement in setting the priorities for cycling mobility in an urban context. AHP hierarchy was built with the help of a panel of experts and stakeholders, that were then involved in the evaluation process trying to make their opinions converge using the Delphi method. A simplified online questionnaire based on the AHP hierarchy was used to involve citizens by eliciting their preferences.
The aim is to propose a custom-made procedure that can be used to involve different categories of stakeholders with different interests and competences.
The remainder of the paper is organized as follows. Section 2 illustrates the materials and methods used to structure the participatory decision-making process; section 3 shows the case study with the involvement of experts, citizens and stakeholders, while section 4 presents and discusses the results of the procedure; section 5 concludes by summarizing the main findings of the paper.

2. Materials and methods

The proposed procedure makes use of different methods and tools in order to be suitable to support expert, citizen and stakeholder involvement in the decision-making process. In particular:

- AHP is here presented to (i) structure the problem into a hierarchy, (ii) elicit stakeholders' preferences and (iii) aggregate them in a collective ranking,
- The Delphi method allows to build consensus among the experts,
- A public meeting is used for information giving and interest gathering,
- An online survey based on AHP hierarchy is made to elicit citizens' preferences.

In the following, AHP and the Delphi method will be explained more in details, while the phases of public meeting and online survey will be illustrated in section 3 with reference to the case study.

2.1. Analytic Hierarchy Process (AHP) for problem structuring

AHP was developed by Thomas Saaty (1980) and it is a process based on pairwise comparisons through the building of matrixes to derive priority scales and weights.
The use of AHP in transport planning is based on the decomposition of a decision-making problem into a tree structured decisions' hierarchy that contains: the general goal of the plan, a set of specific objectives represented by evaluation criteria (and possible sub-criteria) and finally the decision alternatives aimed at achieving the general goal. In general, the problem structure derives from brainstorming sessions with experts or from the analysis or similar problems. A set of pairwise comparison matrices is built by comparing couples of elements at the same level, with respect to the elements of the upper level. The pairwise comparison is made expressing a judgment on a qualitative scale that is turned into a quantitative one (Saaty, 1980). At each level of the problem structure the pairwise matrices can be transformed into a set of local priority vectors using different methods (Saaty and Hu, 1998), e.g. the approximate method, the eigenvalue method, the geometric mean method (Ishizaka and Nemery, 2013). Finally, a ranking of alternatives is obtained by combining all the levels into a global priority vector.
It is known that pairwise comparisons can lead to some inconsistency, meaning that individual judgments can be affected by lack of rationality and violate the consistency condition of the matrix. The inconsistency can be measured (and, therefore, monitored) through the comparison between a Consistency Index derived by the matrix elements with the one obtained by purely random judgments (Saaty, 1980). In general, an inconsistency less than 10% is accepted.
AHP is widely used in transport planning and management (Piantanakulchai and Saengkhao, 2003; Sivilevičius and Maskeliūnaite, 2010; Mahmoud and Hine, 2013; De Luca, 2014). When AHP is used to elicit single decision-maker opinions, the only condition to respect is judgments' consistency; when its use is extended to group decision-making an appropriate procedure to aggregate the individual judgments has to be defined (Dong et al., 2010).
In general, there are four ways to combine multiple preferences into a consensus rating (Ishizaka and Nemery, 2013), according to the level of aggregation (from judgments or from priorities) and the type of aggregation (mathematical or based on consensus vote). The consensus vote can be used when "synergistic" groups are able to agree on the values of the matrices or on the priority vectors. In general, if a consensus cannot be reached, a mathematical aggregation can be

adopted. The problem of aggregation is that the final result consists of an “averaged” ranking that could represent none of the individual points of view.
While mathematical aggregation implies transparency of the calculation and clarity of results but it might not reflect the individual preferences, a consensus vote is a more democratic and fair way to find a group ranking that could have a low rate of acceptance, being supported only by a relative majority.
According to the authors, the optimal solution should be based on a mixed procedure that combines mathematical aggregations with consensus building, through an interaction process among stakeholders that allows a convergence of opinions to increase the acceptability of the final results while at the same time guaranteeing transparency of the decision process (Table 1).

Table 1
Group aggregation procedures.

Type of aggregation	Transparency and reproducibility	Fairness of the process	Probability of acceptance
Mathematical aggregation	✓		low
Consensus vote		✓	low
Consensus building process with the help of mathematical aggregation	✓	✓	high

Source: based on Le Pira (2015)

2.2. Delphi method for consensus building

The Delphi method (Dalkey and Helmer, 1963) is an iterative practice which relies on an anonymous/asynchronous interaction among the participants of a panel performed in different rounds to achieve a convergence of opinions. It has been usually used to elicit experts’ opinions about future trends, but it can be also used as a tool to support consensus building in a group of stakeholders.
A questionnaire is proposed to the members of the panel and at each round of anonymous interaction they are asked to align their opinions within a range where 50% of the opinions stands (between the first and the third quartiles). The iterations are aimed at mitigating radical positions and finding a collective decision which is shared from the panel. The method has been primarily used to elicit experts’ opinions about the future, with the aim to find “real” values, but it can also be used to explore the conditions of consensus building in a group.
Being a practice for the convergence of opinions, it can be combined with other methods aimed at eliciting individual preferences. An interesting approach is the one that combines Delphi practices with multi-criteria decision-making methods, such as AHP (Tavana et al., 1993; Vidal et al., 2011) or ANP (Analytic Network Process) (García-Melón et al., 2012).
In this study, a Delphi procedure is combined with the AHP method, to elicit preferences of experts and stakeholders about sustainable transport strategies and to see if the anonymous interaction could lead to a convergence of opinions. In this respect, there are multiple ways to measure consensus derived from Delphi, some based on qualitative analysis and others on descriptive statistics (von der Gracht, 2012). With AHP, from the judgments in terms of pairwise comparisons, vectors of preferences are derived. In this case, to measure consensus, the overlap between vectors of preferences can be used, being a simple indicator of the similarity between two stakeholders’ opinions (Le Pira et al., 2015). In this study the concept of average overlap will be used to measure the similarity of opinions and to what extent the interaction may affect the degree of achieved consensus towards the final decision.

3. Case study

3.1. Cycling mobility in Catania

In the last years cycling mobility has been receiving more attention from policy-makers as a sustainable and efficient mode of transport in urban areas. Many cities are adapting to introduce facilities and infrastructures for cyclists, but still lots have to be done, in particular in car-addicted cities. The case study refers to a participation experiment with experts, stakeholders and citizens involved in several phases to study strategies to promote cycling mobility in Catania, a medium-sized city (300,000 inhabitants) located in the eastern part of Sicily, Italy. Critical issues related to transport in Catania include road traffic congestion, low public transit ridership, little diffusion of cycling and walking for systematic trips, and high levels of fuel consumption and greenhouse gas emissions per capita (Ignaccolo et al., 2016).
In the last years, the interest for cycling mobility of individual citizens and different associations has been raising, giving birth to several initiatives and exerting pressure on the public administration to increase cycling facilities and improve the safety conditions of cyclists.
For all these reasons, a participation process was performed involving experts, stakeholders and citizens in order to understand the priority of cycling mobility strategies in Catania, paving the way for a more engaging and continuous participation in the transport policy-making process.

3.2. Combined expert, stakeholder and citizen involvement for priority setting of cycling mobility strategies

The whole participatory process is summarized in **Error! Reference source not found.**.

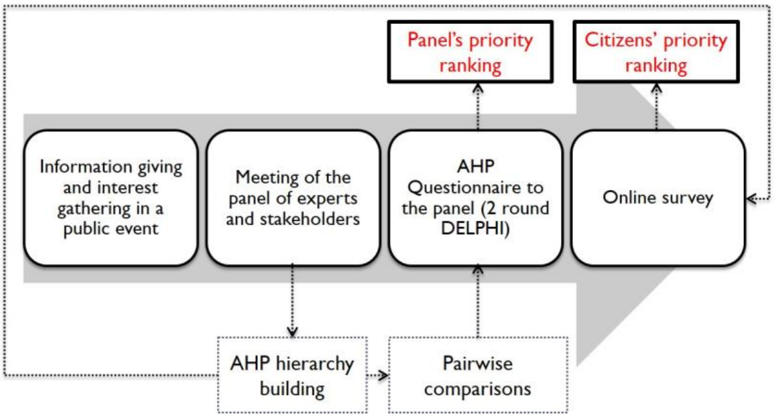


Fig. 1.
Different phases of the participatory process
Source: own setup

The initiative was presented to citizens in a public meeting within the "Catania Bike Festival" (May 2015). Information was given to the audience and interest was gathered by collecting names and contacts of people willing to participate at the initiative.
After this first preliminary phase, a given number of transport experts and stakeholders was involved to identify policy measures that can promote cycling mobility in the city of Catania. The panel of experts and stakeholders met in a brainstorming session (July 2015) to analyze the problem, structuring it into a four-levels hierarchy (Fig. 2). They agreed that four different criteria were necessary to evaluate the alternative measures, i.e. the criteria representing the three dimensions of sustainability (environmental, social and economic) and a transport criterion. Seven indicators were chosen to represent the four criteria and then the alternative measures to promote cycling mobility were identified from the panel:

1. Building a comprehensive cycling network,
2. Setting up extended 30 km/h zones,
3. Making information and education campaigns, to increase public awareness towards pros of cycling mobility,
4. Funding citizens to buy electric bicycles,
5. Establishing a city bike sharing service.

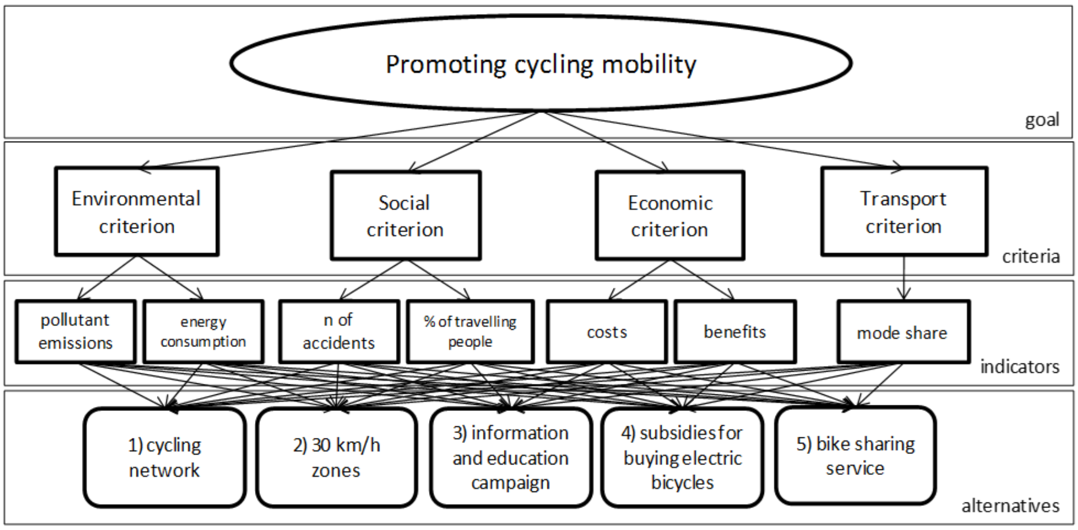


Fig. 2.
Hierarchy of the problem "promoting cycling mobility"
Source: Le Pira et al. (2016b)

After structuring the decision-making problem into a hierarchy, each member of the panel was asked to make judgments in terms of pairwise comparisons between the elements of each level of the hierarchy. Due to the great number of answers they had to give (a total of 79 pairwise comparisons), the facilitator guided them into the whole process paying attention to the consistency of their judgments.

The results derived from AHP were analyzed in order to go on with the first iteration of the Delphi method. In particular, for each pairwise matrix, the local priority vectors were derived, the first quartile (corresponding to the 25% of judgments) and the third quartile (corresponding to the 75% of judgments) were chosen as reference numbers for the members of the panel to “align” their judgments in the second iteration.
By doing this, the results could be expressed in terms of priority vectors for each level of the hierarchy. By aggregating them, the new priority vector for the group was derived, representing the alternative ranking of the panel of experts and stakeholders involved. The whole procedure with the results is described more in details in Le Pira et al. (2016b).
Based on the AHP hierarchy, a simplified questionnaire was structured in order to elicit citizens’ judgments through an only survey (January 2016). In particular, they were asked to rank the four different criteria (environmental, social, economic and transport) with respect to the goal of promoting cycling mobility; then, each alternative was evaluated with respect to the four criteria by stating their relative contribution in achieving the goal (very low, low, average, high, very high). The elements were not compared in pairwise comparisons because of the great number of answers required (as already said, 79 pairwise comparisons).

4. Results and discussion

Results, in terms of collective rankings of alternatives, were obtained in two different ways, according to the questionnaire:

- In the AHP questionnaire the row geometric mean method (RGMM) was used as prioritization procedure and the Aggregation of Individual Priorities (AIP) was used to aggregate the individual rankings (Dong et al., 2010),
- In the simplified online questionnaire, the individual rankings were obtained by transforming the qualitative judgments in quantitative measures (e.g. “very low” corresponds to 1, while “very high” is 5), while the aggregation of individual preferences was done using the Borda rule[2] (Borda, 1781).

The results of the questionnaires in terms of collective rankings (per involved category) and related overlap values are presented in Table 2. It is worthy of notice that the overlap is a measure of the similarity between the individual ranking and the collective one derived from aggregation. Being a simple measure based on the scalar product between vectors of preferences, it assumes a finite value, comprised between -1 (totally different rankings) to +1 (exactly equal). For more details, see Le Pira et al., (2015, 2016b). The first collective ranking resulting from the panel of experts and stakeholders shows very high values of overlap (0.74 compared with the maximum reachable value of 1). This is due to the fact that the actors involved showed more or less the same level of competence and objectives, even if there are some differences in the individual rankings. After the second round of the Delphi method, there is an increase in the convergence of opinions and this confirms the effectiveness of interaction for the consensus building process.
The ranking of alternatives derived from citizens is significantly different from the one derived from the panel of experts and stakeholders, showing that they have diverse views about the priorities for cycling mobility. In particular, while the panel agreed that setting up extended 30 km/h zones is the priority to increase the share of cycling mobility, the priority for citizens is to build a comprehensive cycling network followed by the establishment of a bike sharing service (which is one of the lowest priority interventions according to the panel). The difference in the results is also due to a different level of competence and understanding of the problem: while the members of the panel analyzed the problems together and discussed the different alternatives before expressing their preferences, citizens were only involved via an online questionnaire with a short description of each alternative. In this respect, it can be argued that the involvement of experts and stakeholders was much deeper than the citizens one, i.e. the former participated in the decision-making process, while the latter were only consulted. Besides, citizens overlap is much lower than the panel’s one (0.25 versus 0.80). This is because (a) a higher number of citizens with (b) heterogeneous interests were interviewed and (c) without interacting between each other.
A small sample of University students (13) was also interviewed to test the suitability/adaptability of the two questionnaires. Even though they were involved in Transport Studies they did not analyze the problem before giving their judgments, so their level of interest in the decision (as citizens) can be considered higher than their competence. They were asked to answer to both of the questionnaires (AHP and simplified) and the difference in their judgments was tested. The collective ranking obtained with the simplified questionnaire is more in line with individual preferences, suggesting that a simpler, easier to understand questionnaire is to be preferred when a non-expert/non-informed audience is involved.

[2] With the “Borda Rule” the collective ranking is obtained on the basis of the sum of different scores assigned to each alternative in order to reflect the individual preferences’ ranking (e.g., if there are three alternatives A, B and C and the individual ranking is A>B>C, then A=3, B=2 and C=1).

Table 2
Results.

Stakeholders involved	Number	Online survey	AHP questionnaire	
			I round	II round (Delphi)
Citizens	82	1>5>4>3>2 (overlap 0.25)	-	-
Students (test)	13	1>5>4>2>3 (overlap 0.48)	1>2>5>4>3 (overlap 0.38)	-
Delphi Panel (Experts & stakeholders)	7	-	2>1>3>5>4 (overlap 0.74)	2>1>3>5>4 (overlap 0.80)

Source: own setup

5. Conclusions

A tailored approach is needed to elicit expert, stakeholder and citizen preferences, while using solid decision-support methods. MCDM methods, such as AHP are useful to (1) structure the problem (from the goal(s), to the criteria, indicators and alternatives), together with the experts (and stakeholders), (2) elicit their preferences, e.g. in terms of importance weights about the elements that compose the problem and (3) derive group priority rankings that can aid the decision-making process. Besides, a combination of MCDM with participation methods (i.e. Delphi-AHP method), proved to be suitable to support complex group decision-making processes. In this respect, the cooperation of the panel of experts in structuring the problem and sharing criteria, relevant indicators and alternative measures increased the probability to have a good convergence of opinions after only one step of anonymous interaction. A simplified online questionnaire based on the AHP hierarchy was used to consult citizens by eliciting their preferences. The priority ranking derived from citizens is significantly different from the one derived from the panel, showing that they have diverse views about the priorities for cycling mobility in the city of Catania.
In conclusion, this paper illustrated the first test of a procedure that, in principle, can support a more diffuse involvement of stakeholders in transport decision-making process, considering the heterogeneity of their interests and competences.

References

De Borda, J.C. 1781. *Memoire sur les elections au scrutiny*. Historoire de l'Academie Royals des Sciences, Paris, France.

Cascetta, E.; Cartenì, A.; Pagliara, F.; Montanino, M. 2015. A new look at planning and designing transportation systems: A decision-making model based on cognitive rationality, stakeholder engagement and quantitative methods, *Transport Policy*, 38: 27-39.

Dalkey, N.; Helmer, O. 1963. An Experimental Application of the Delphi Method to the Use of Experts, *Management Science*, 9(3): 458-467.

De Luca, S. 2014. Public engagement in strategic transportation planning: An analytic hierarchy process based approach, *Transport Policy*, 33: 110-124.

Dong, Y.; Zhang, G.; Hong, W.; Xu, Y. 2010. Consensus models for AHP group decision making under row geometric mean prioritization method, *Decision Support Systems*, 49: 281-289.

Ettema, D. 2015. *Complexity methods applied to transport planning*. In: Furtado, B. A.; Sakowski, P. A. M.; Tóvolli, M. H. (Eds.). *Modeling complex systems for public policies*. Ipea, Brasília, Brasil.

Franceschini, S.; Marletto, G. 2015. Assessing the benefits and the shortcomings of participation – findings from a test in Bari (Italy), *Journal of Transport Geography*, 44: 33-42.

García-Melón, M.; Gómez-Navarro, T.; Acuña-Dutra, S. 2012. A combined ANP-delphi approach to evaluate sustainable tourism, *Environmental Impact Assessment Review*, 34: 41-50.

Ignaccolo, M.; Inturri, G.; Le Pira, M.; Caprì, S.; Mancuso, V. 2016. Evaluating the role of land use and transport policies in reducing the transport energy dependence of a city, *Research in Transportation Economics*, 55: 60-66.

Ishizaka, A.; Nemery, P. 2013. *Multi-Criteria Decision Analysis-Methods and Software*, John Wiley & Sons, New York, U.S.A.

Kelly, J.; Jones, P.; Barta, F.; Hossinger, R.; Witte, A.; Christian, A. 2004. Successful transport decision-making - A project management and stakeholder engagement handbook, Guidemaps consortium. Available from Internet: <http://www.civitas.eu/content/reports-and-resources-guidemaps-successful-transport-decision-making-project-management-and >.

Le Pira, M. 2015. Towards participatory decision-making processes in transport planning: an agent-based approach. University of Catania, Italy. Availabe from Internet: <https://www.researchgate.net>.

Le Pira, M.; Inturri, G.; Ignaccolo, M.; Pluchino, A.; Rapisarda, A. 2015. Simulating opinion dynamics on stakeholders' networks through agent-based modeling for collective transport decisions, *Procedia Computer Science*, 52: 884-889.

Le Pira, M.; Ignaccolo, M.; Inturri, G.; Pluchino, A.; Rapisarda, A. 2016a. Modelling stakeholder participation in transport planning, *Case Studies on Transport Policy*, 4(3): 230-238.

Le Pira, M.; Inturri, G.; Ignaccolo, M.; Pluchino, A. 2016b. Modelling consensus building in Delphi practices for participated transport planning. In *Proceedings of WCTR2016*.
Mahmoud, M.; Hine, J. 2013. Using AHP to measure the perception gap between current and potential users of bus services, *Transportation Planning and Technology*, 36(1): 4-23.
Piantanakulchai, M.; Saengkhao, N. 2003. Evaluation of alternatives in transportation planning using multi-stakeholders multi-objectives AHP modelling. In *Proceedings of the Eastern Asia Society for Transportation Studies*.
Quick, K.S.; Narváez, G.E.; Saunoi-Sandgren, E. 2015. Changing Minds through Deliberation: Citizens' Accounts of Their Changing Local Transportation Policy. In *Proceedings of the TRB 94th Annual Meeting Compendium of Papers*.
Rowe, G.; Frewe, L.J. 2000. Public Participation Methods: A Framework for Evaluation, *Science, Technology, & Human Values*, 25(1): 3-29.
Rucker, D.G. 2014. Online Public Participation Platforms and Applications (Overview). White paper - Wise Economy Workshop & New World Public Engagement. Available from Internet: <http://wiseeconomy.com/wp-content/uploads/2014/03/Online-Engagement-Platforms-White-Paper-WEW-03-14-14.pdf>.
Saaty, T.L. 1980. *The Analytic Hierarchy Process*, McGraw Hill, New York, U.S.A.
Saaty, T.L.; Hu, G. 1998. Ranking by Eigenvector Versus Other Methods in the Analytic Hierarchy Process. *Applied Mathematics Letters*, 11(4): 121-125.
Sivilevičius, H.; Maskeliūnaite, L. 2010. The criteria for identifying the quality of passengers' transportation by railway and their ranking using AHP method, *Transport*, 25(4): 368-381.
Tavana, M.; Kennedy, D.T.; Rappaport, J.; Ugras, Y.J. 1993. An AHP-Delphi Group Decision Support System Applied to Conflict Resolution in Hiring Decisions, *Journal of Management Systems*, 5: 49-74.
Vidal, L.; Marle, F.; Bocquet, J. 2011. Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects. *Expert Systems with Applications*, 38: 5388-5405.
Von der Gracht, H. A. 2012. Consensus measurement in Delphi studies. Review and implications for future quality assurance, *Technological Forecasting & Social Change*, 79: 1525-1536.
Wilcox, D. 1994. *The guide to effective participation*, Partnership Books, London, UK.

A NEW STRATEGY FOR THE DESIGN OF BICYCLE PATHWAYS NETWORKS

Marco Petrelli[1]
[1] *University of Roma Tre, Roma, Italy*

Abstract: In the last years there was an increase of interest of decision makers about bicycle use as alternative travel mode to the predominant auto mode. Starting from these considerations, the objective of the research is the development of a procedure for the definition of bicycle facilities in terms of bicycle pathways. The goal is the increase of the attractiveness of cycling developing a safe and of quality bicycle network for cities characterized by cities with poor level of facilities for bicycle and a very low current bicycle share of trips. A preliminary phase of identification of the bicycle users' needs has been carried out by means of a specific experimentations of 18 months, based on the creation of the travel diary of 30 bicycle users from the city of Rome. Such data are related to the comparison between shortest and observed paths, the use of existing bicycle infrastructures, the characteristics of the links of the road network shared with cars. The design methodology is based on the hypothesis that bicycles are obliged to travel sharing the road sections with other components, using dedicated pathways only for a part of the travel. Such approach permits also to explicitly take into account the significant budget constraints of local administrations.

Keywords: sharing roads, bicycle facilities, road safety, bicycle users behaviour.

1. Introduction

In the last years, the interest of decision makers about bicycle use as alternative travel mode to the prevailing auto mode is more and more increasing. The changes of the urban patterns with a continuous spread of residences and activities, an increasing complexities of the travel behaviour of the people have produced in many urban areas unsustainable urban mobility practices. Negative impacts on sustainability and traffic congestions require new and different policies to promote the use of alternative modes as public transport and cycling.
Based on such issues, this paper presents a new strategy for the definition of the network of bicycle pathways. The objective of the procedure is to build a safe and of quality bicycle network in which traveling from any origin to any destination should be convenient and quick involving a safe and pleasant experience. The proposal for the bicycle network construction is related only to bicycle users with utilitarian purposes (commuters) and should be associated to cities with poor level of facilities for bicycle and a very low current bicycle share of trips. Cities with these characteristics have to be considered a specific case in which the development of cycling infrastructures, following existing standards, should be impossible or ineffective due to the limited number of cyclists. In fact, bicycle lanes come at the expense of restricting the motorists to less space, which may lead to a much worse traffic circulation and hence more severe congestion. This sincere fear has precluded the introduction of bicycle lane in many cities (Alliance for Biking & Walking, 2014). These challenges are really important in congested urban networks. In uncongested urban networks, bicycle lanes cause no congestion and are relatively unproblematic. Instead in congested urban networks, bicycle lanes are more contentious, involving debates about the use of a portion of the road space reserved for cyclists (Bagloee et al., 2016).
The procedure developed is based on the identification of the critical issues and the best planning approach to adopt in these specific cities for designing the bicycle network. In particular, such information are derived from an analysis of literature review, data about bicycle users' needs and safety issues identified for the city of Rome. Taking into account the specific characteristics about mobility (few cyclists and congestion on the road network), this urban area can be considered a valid case of study representative of conditions of many cities all around the world.
The structure of this paper is based on the following different steps: firstly, the state of the art about the development of infrastructures for bicycles and policies to promote cycling is shown. The third section deals with the analysis of these challenges in the specific case of the city of Rome. Finally, the new proposal is illustrated identifying the possible evolution of the bicycle network inside urban areas.

2. Literature review

In literature, especially in the last decade, it is possible to find many contributions about effective measures on promoting bicycling. Many of these contributions highlighted the importance of the presence of infrastructures for cyclists. Nelson and Allen (1997) found a positive association between miles of bicycle pathways per 100,000 residents and the percentage of commuters using bicycle. This result derives from the cross-sectional analysis of 18 US cities data. The successive analysis performed by Dill and Carr (2003) with data from 43 large cities across the US, confirms that higher levels of bicycle infrastructures are positively and significantly correlated with higher rates of bicycle commuting. Pucher et al. (2011) found that cycling rates have risen much faster in the cities that have implemented a wide range of infrastructure and programs to promote cycling and increase cycling safety: expanded and improved bike lanes and paths, traffic calming, parking, bike-transit integration, bike sharing, training programs, and promotional events. Sanders (2016) presents results from an internet survey about perceived comfort while driving and bicycling on

[1] Corresponding author: marco.petrelli@uniroma3.it

various roadways. The roadways with barrier separated bicycle lanes were the most popular among all groups, regardless of bicycling frequency. According to the Collection of Cycle Concepts (Andersen et al., 2012) from Denmark, the combination of hard and soft measures is crucial to bring about a significant change in citizens' transport habits and road safety behaviour. Such considerations are also validated from Vandenbulcke et al. (2011) with an extensive analysis of cycle commuting in Belgium. These found that only a combination of several measures (promotional campaigns, improvement of cycling facilities, etc.) will really lead to an increase in cycle commuting. Munoz et al. (2016) study for understanding the key factors influencing bicycle commuting in an environment characterized as in transition to become a cyclable city. The authors suggest prioritising marketing campaigns and other infrastructure investments (cycleways and bicycle parks) around leisure zones and social and cultural centers to maximise the significant influence of friends on bicycle commuter behaviour. According to these analysis, it is possible to underline that not only facilities but especially active, complementary pro-bicycle policies should be essential to promote the use of the bicycle.

About the experience of European bicycle use, the European Commission report (1999) about cycling indicates that the really incompatible situation for the bicycle's use are few. The presence of strong slopes (6-8% for tens of meters) and some climatic elements as the snow, a thunderstorm or a very hot and sultry day seem to be the only factors that have a dissuasive impact for the use of the bicycle. In many cases, especially where the bicycle use is modest, the main obstacles to boosting the bicycle as a regular mode of transport are safety concerns due to interactions with motorized traffic (Buehler and Dill, 2015; Habib et al., 2014; Menghini et al., 2010). Several studies have shown that it is really emerging the evidence about "safety in numbers". Taking into account data from Amsterdam and Copenhagen, cycling is generally very safe in both cities (Bicycle account, 2012). From 2007-2012, there has been on average five fatalities among cyclists in Amsterdam and three in Copenhagen, which corresponds to the difference in the urban population. Also Jacobsen (2003) suggests that cities with higher bicycling rates also have better road safety records. This study attempts to better understand this phenomenon of lower fatality rates in bike-oriented cities by examining 11 years of road safety data (1997–2007) from 24 California cities. Cities with a high bicycling rate among the population generally show a much lower risk of fatal crashes for all road users when compared to the other cities analysed. The fact that this pattern of low fatality risk is consistent for all classes of road users strongly suggests that the crashes in cities with a high bicycling rate are occurring at lower speeds. According to Marshall and Garrick (2011), motorists adjust their behaviour in the presence of people walking and bicycling. Since it is unlikely that the people walking and bicycling become more cautious if their numbers are larger, it indicates that the behaviour of motorists controls the likelihood of collisions with people walking and bicycling. Policies that increase the numbers of people walking and bicycling appear to be an effective way to improving the safety of people walking and bicycling.

3. Bicycle users' needs and safety issues in Rome

The urban area of Rome is characterized by a population of about 2.9 million and 1.1 million of employees, producing about 550,000 trips in the morning peak hour. Taking into account the built environment, the city should be considered as divided in 4 different circular areas, starting from the historical center to the more external one, outside the GRA (a circular freeway of approximately 68 km of length). The average population density is not so high (about 61.5 persons/ha) but there is a very large variation from center to outside areas. Outside the GRA, in a very large area (about 90,000 ha) the density decreases to very low values, about 6 persons/ha, even if the population of this external area is larger than half a million of persons. In terms of employees, about half of the total amount is distributed in the peripheral districts, also situated outside of the GRA.

About the mobility system, Rome has a very high level of vehicle ownerships (more than 850 for 1,000 persons). The modal share of private vehicles (auto+motorcycle) is more than 65%, the public transport share is estimated to be around 30% while the bicycle share is only 0.6%. Depending on these habits, the road network is frequently characterized by congested conditions. Large part of the historical centre of the city, one of the main point of concentration of activities, is a traffic limited zone (ZTL) and the access in the area is permitted only to the residents' cars. In many districts of the city, there is a relevant lack of space for parking; this trouble is partially offset by the extensive use of motorcycles.

The network of bicycle pathways is currently extended for 125 km (see Fig. 1), with very limited length especially if compared with the extension of the road network (7,530 km). Such situation is also exacerbated by the specific development of the bicycle lanes, generally located in green areas or along the Tiber river with very few sections in the built areas. This lack is due to many, complementary aspects as the presence of not so wide road sections, the high level of congestion in the car network, the widespread use of the road network for the cars parking and the poor level of sidewalks largely used by pedestrians.

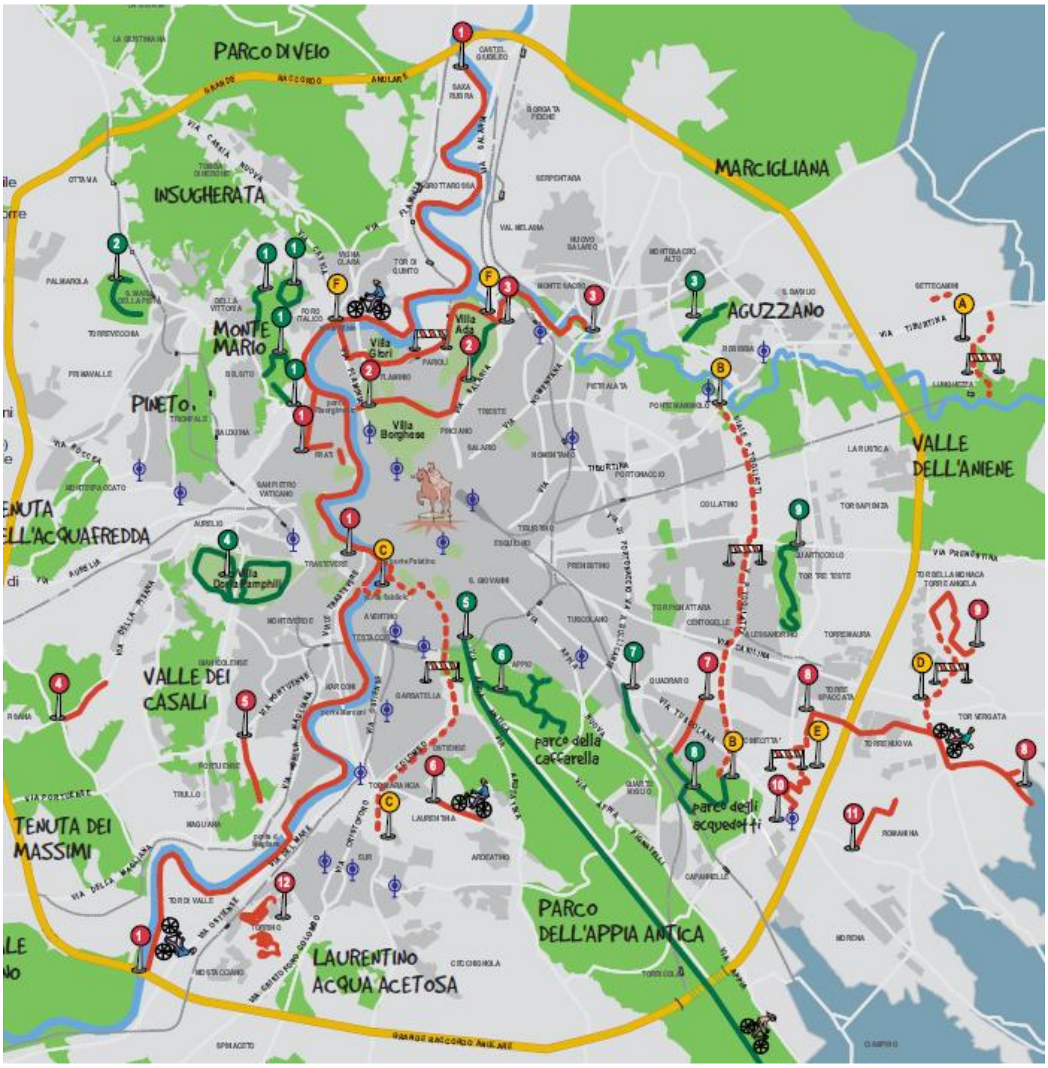


Fig. 1.
The bicycle pathways network in the city of Rome
Source: Rome Mobility Agency website

A preliminary phase of identification of the bicycle users' behaviour and needs has been carried out by means of a specific experimentations of 18 months of 30 bicycle users from the city of Rome. The users, selected among the students and the employees of the Roma Tre university, have been involved with the creation of their own travel diary. The resulting set of users selected is well representing the commuters actually using the bicycle in the city with a very large prevalence of young males. The analysis of the travel diaries, carried out by the users, have permitted to identify the paths used and the trips characteristics. In 18 months, the 30 bicycle users have travelled for about 29,000 km with an average trip length of 6.01 km. Taking into account each specific trip recorded, on average the chosen paths are 15.4% longer than the shortest paths, involving the use of the bicycle pathways only for 3.3% of the length while the use of multilane roads is 59.2%. Such data permits to underline the behaviour of the cyclists that are very sensitive to travel distance, searching, very often, to reduce travel distance also by adopting unsafe behaviour and not respecting the traffic rules. Such data from travel diaries allows also to observe that in the city of Rome, there is a significant lack of specific solutions for cyclists (for instances routes for avoiding physical and infrastructural obstacles, dedicated rules for the one-way streets, etc). This condition is also confirmed by the observation that longer trips correspond to larger differences between chosen and shortest paths, in many cases derived by the increasing number of obstacles to overcome.

About the safety issues in the city of Rome related with cyclists, the information on collisions experienced by the cyclists over the years from 2005 to 2015 have been collected using accidents database from Rome Mobility Agency. Accidents taken into account are defined as event in which a bicycle is involved regardless of fault and eventual interference with any other object. In the last years, data show that about 300 accidents occurred during a year with 5 bicyclists killed in crashes with motor vehicles. The analysis of the data at disposal from 2005 to 2015 (see Fig. 1 and Table 1) shows that the accidents, people killed and injured are in slight increase, probably due to the increasing number of cyclists in the city. 73% of accidents occur in daylight and they are for the 89%, collisions between car and bicycle. About the people involved in these collisions, male is the 85% of casualties, representing the very large majority of users, while old people are 13.5% of casualties but represents 40% of fatalities. These data show clearly that bicycle users safety issues in the city of Rome are related to the complex and very hard relationships with motorists, involving dangerous conditions especially for older cyclists. As shown by Rasanen and Summala (1998), two common mechanisms, the allocation of attention and the unjustified expectations about the behaviour of others, can be considered essential to understand car-bicycle accidents. In older people, slower reaction time in combination with the two mechanisms already reported should explain the data on fatalities and the unsafe conditions of travel for older cyclists in the road network of Rome.

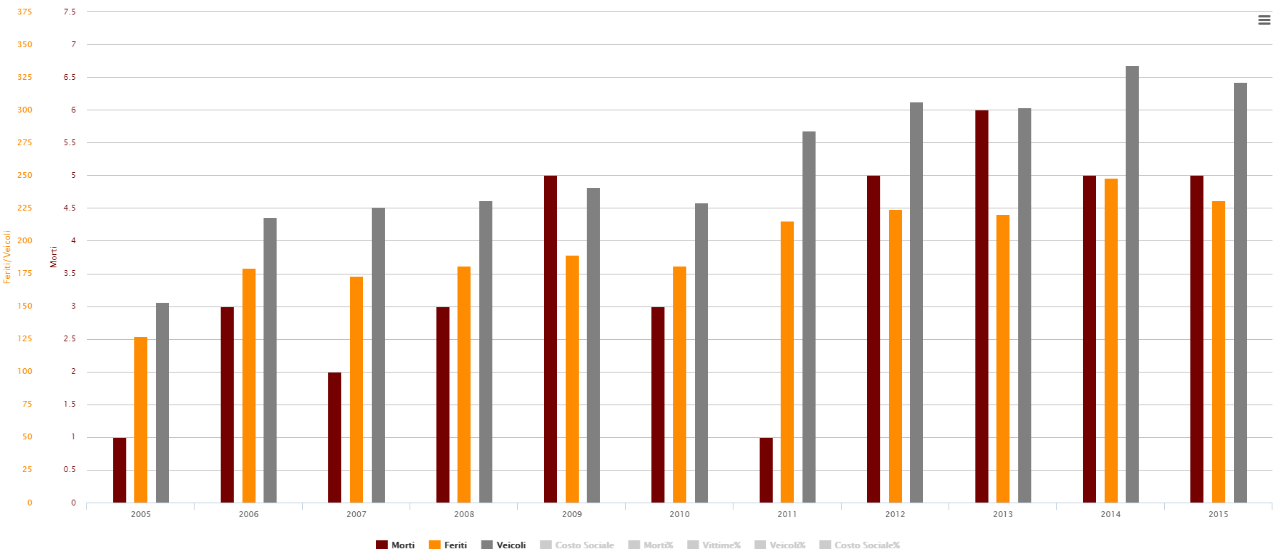


Fig. 1.
Cyclist accidents from 2005 to 2015 in the city of Rome
Source: Rome Mobility Agency

Table 1
Cyclist accidents from 2005 to 2015 in the city of Rome

Year	Cyclist accidents (#)	Killed (#)	Injured persons (#)
2005	153	1	127
2006	218	3	179
2007	226	2	173
2008	231	3	181
2009	241	5	189
2010	229	3	181
2011	284	1	215
2012	306	5	224
2013	302	6	220
2014	334	5	248
2015	321	5	231

Source: Rome Mobility Agency

Fig. 2 shows information about the location of accidents, disaggregated in accidents without fatalities (points in red) and accidents with fatalities (points in purple). The majority of accidents occurred in the city centre, due to higher numbers of people travelling by bicycle, but fatalities are usually located outside the city centre, especially on the multilane roads. Most of the accidents occurred for the 54% on streets, generally on the main roads, and only 37.5% are located on intersections. Similar data are also valid for fatalities: 68% of these are recorded on streets and only 24% on intersections. Most of the studies showed a totally opposite situation in which the intersections are generally known as black spots for cyclists as well as for all road users (Vandenbulcke et al., 2014; Wang and Nihan, 2004; Quddus, 2008). Such places are characterized by an higher risk of having an accident compared to the rest of the network for the presence of many potential conflict points.

About the safety issues for cyclists in the city of Rome, it is possible to undoubtedly highlight that generally can be considered an unsafe environment with a very high number of accidents and fatalities respect to other cities in North of Europe with a totally different number of commuters by bicycle. This is mainly due to the complexity of the traffic situation, the more aggressive driving behaviour and the limited space left to the cyclists. Such differences with other cities are obviously amplified by the lack of facilities for bicycle but also by the negative impacts related to the modest number of cyclists. In fact, such condition involves, for the motorists, the increased risk of collisions with bicycle due to the unexpected presence of cyclists. The risk of accidents is also related to the specific behaviour of cyclists: it is clear that the risk perception and also the attention allocation are devoted especially to the intersections, with an unexpected positive result in terms of accidents. Less attention is instead focused on travelling on the streets where unsafe conditions are mainly due to the lack of dedicated spaces, the motorists behaviour in the shared roads and also the unexpected presence of cyclists.

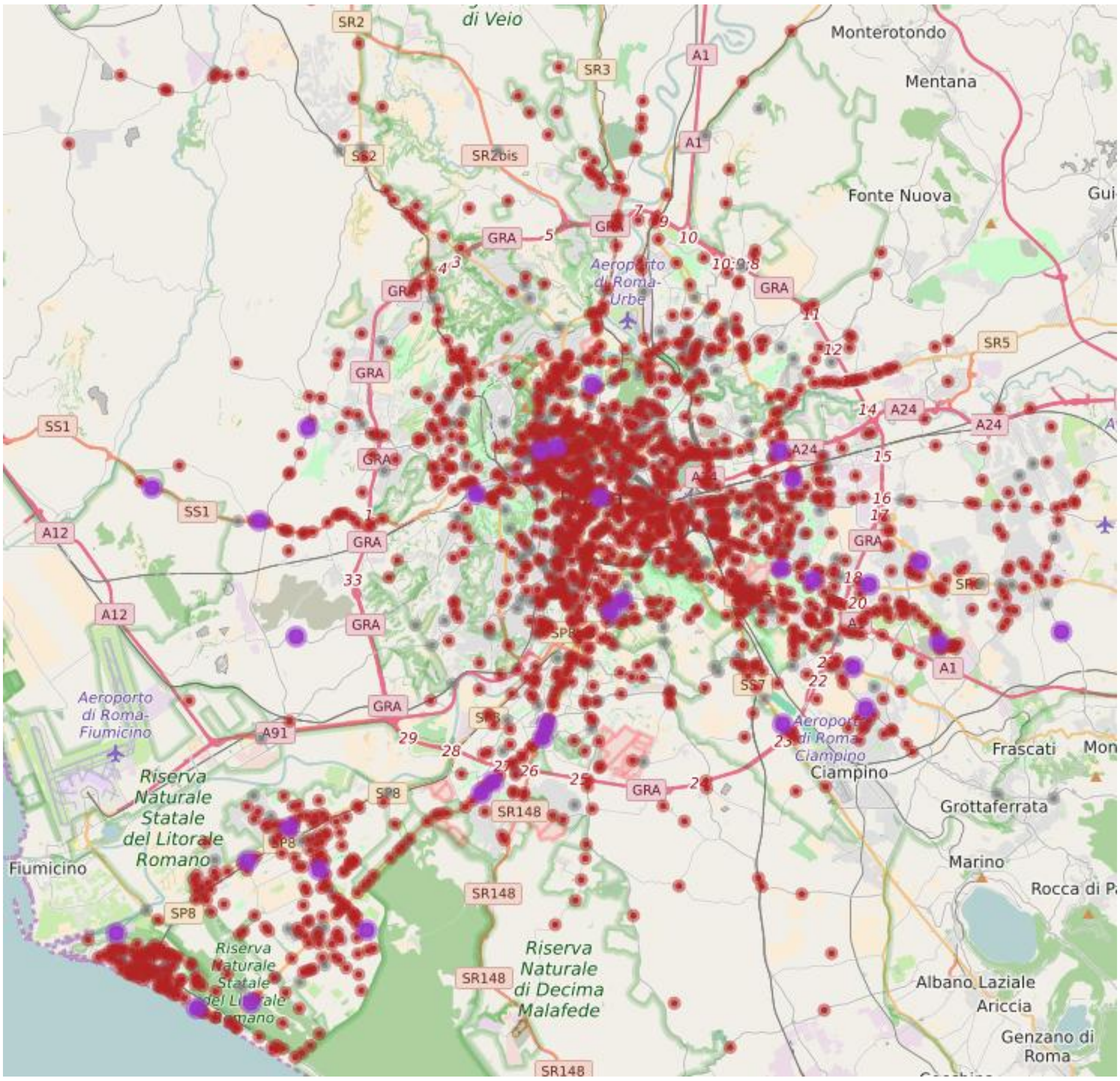


Fig. 2.
Location and severity of cyclist accidents from 2005 to 2015 in the city of Rome
Source: Rome Mobility Agency

4. Innovative strategy for the development of pathways network

Taking into account the specific context of the study, cities with poor level of facilities for bicycle and a very low current bicycle share of trips, it is possible to observe that the main critical issues related to bicycle use for commuters are the lack of dedicated facilities not only pathways but also parking spaces. In many cases as in Rome, these problems are enlarged by the ineffective existing pathways, often built where it is possible without subtracting spaces at the other components, so producing the effect that cyclists avoid the use of these for the too long and too slow trips associated. In such context, cyclists are also to consider as vulnerable users of the road network for their “few numbers”. The safety issues are perceived as the main critical point by the potential cyclists especially without a satisfactory development of the pathways network. Past experiences analysed have shown also the limited success of action based only on building new pathways without a more comprehensive policy to really sustain cycling.
The improvement of cycling condition to promote the use of bicycle for commuters requires the involvement and the coordination of many elements in cycling-related infrastructure, operations and services. Through a collaborative effort among these elements it is possible to provide a comprehensive range of strategies in many sectors. Of course, the main controversial point is about the facilities development that can be solved by using a new innovative strategy. The proposal is to stress the concept that bicycle users have to share road section with other components as more as possible, avoiding any request of useless dedicated spaces. In this context, dedicated bicycle pathways have to be realized only where really necessary to travel in a safe and comfortable way. North European best practices about

facilities can represent an ideal target for long term period, after cities transformation in cyclabe cities, but in the short and medium term period, has to be considered an experience not replicable.
The sharing of road section between bicycles and motorists is possible by creating better compatibility conditions. The compatibility of different vehicles or road users is related to their mass and speed. The smaller these differences, the more compatible are road users. In other words, the sharing of road section in safe condition should be possible by achieving the principle of 'homogeneity'. This states that where road users or vehicles with large mass differences use the same traffic space, the speeds should be so low that the most vulnerable road users and transport modes come out of a collision without any severe injuries (Wegman et al., 2012). Several studies have confirmed that there is a threshold around 30 km/h, above which the probability of injury and fatality for cyclists colliding with motorists strongly increases (Kim et al., 2007).
Starting from these consideration, the innovative strategy to follow derives from the development of a combination of new pathways and actions involving the road network management. About the need of dedicated pathways, the selection of this category of pathways is related to two main different aspects: safety and mobility reasons. The first is involving safety issue in multilane roads with speed equal or larger than 50 km/h while the second refers to the bicycle network connection to avoid too long route using road network or in case of presence of physical and infrastructural obstacles. It is also important to minimize the sharing of facilities dedicated to pedestrians because the speed of cyclists and pedestrians are different and because, in many cases, the very large number of pedestrians or the little space at disposal reduce the convenience of sharing spaces.
In conclusion, according to this strategy, it is possible to identify three main categories of pathways:

a) No separation for different road users, the road section is shared with cars without any specific marking. This is the typical condition of narrow street in the historical center or local roads with maximum speed limited to 30 km/h,
b) No separation for different road users, the road section is shared with cars and public transport vehicles but there is the need of bicycle preferentiality using horizontal markings and traffic signs combined with some specific restrictions for cars movement,
c) Segregation of bicycles with the creation of a two-ways or one-way pathway completely separated from other traffic components roads.

The category b) of pathways represents the skeleton of the bicycle network. His design requires the development of a network of links to provide direct, logical and convenient connections combined with actions to manage traffic circulation in the road network. The aim is to divert part of the cars traffic or to reduce average vehicles speed with new restrictions for cars as lower speed limit, narrow lanes increasing parking spaces, reduction of permitted turns at intersections, etc.

5. Conclusion and further developments

This paper presents a new strategy for the definition of the network of bicycle pathways. The objective is to develop a safe and of quality bicycle network for bicycle users with utilitarian purposes in cities with poor level of facilities for bicycle and a very low current bicycle share of trips. The new strategy focuses attention to the concept that bicycle users have to share road section with other components as more as possible, avoiding any request of useless dedicated spaces.
Further efforts have to be done in two different directions. Firstly, it is important to identify the need in terms of management measures and the impact of these to ensure safety condition for sharing spaces. Then, it is necessary to define a procedure for the bicycle pathways network design. Such can be identified by an iterative procedure based on search and selection of shortest paths. The design methodology should be organized as an iterative procedure that, starting from an initial set of pathways composed by the shortest paths, improves the solution proposed by realigning the bicycle pathways, eliminating the less efficient and not necessary ones according to the resulting pathways spatial layout (directness, length, width, possible duplication, etc.) and the characteristics of the road network (traffic volumes and composition, road section and traffic average speed, etc).

References

Alliance for Biking & Walking. 2014. *Bicycling and Walking in the United States: 2014 Benchmarking Report*, Alliance for Biking & Walking, Washinton DC, U.S.A.
Andersen, T.; Bredal, F.; Weinreich, M.; Jensen, N.; Riisgaard-Dam, M.; Kofod Nielsen, M. 2012. *Collection of Cycle Concepts,* Cycling Embassy of Denmark, Copenhagen, Denmark.
Bagloee, S.A.; Sarvi, M.; Wallace, M. 2016. Bicycle lane priority: Promoting bicycle as a green mode even in congested urban area, *Transportation Research Part A*, 87: 102-121.
Buehler, R.; Dill, J. 2016. Bikeway networks: a review of effects on cycling, *Transport Reviews*, 36: 1-19.
City of Copenhagen 2012. *Copenhagen, City of cyclists: Bicycle account 2012*, Technical and Environmental Administration, Traffic Department, Copenhagen, Denmark.
Dill, J.; Carr, T. 2003. Bicycle commuting and facilities in major US cities – If you build them, commuters will use them, *Transportation Research Record*, 1828: 116-123.

European Commission 1999. *Cycling: the way ahead for towns and cities - A handbook for local authorities*, European Commision, Brussels, Belgium.

Habib, K.N.; Mann, J.; Mahmoud, M.; Weiss, A. 2014. Synopsis of bicycle demand in the City of Toronto: investigating the effects of perception, consciousness and comfortability on the purpose of biking and bike ownership, *Transportation Research Part A*, 70: 67-80.

Jacobsen, P.L. 2003. Safety in numbers: more walkers and bicyclists, safer walking and bicycling, *Injury Prevention*, 9(3): 205-209.

Kim, J.K.; Kim, S.; Ulfarsson, G.F.; Porrello, L.A. 2007. Bicyclist injury severities in bicycle–motor vehicle accidents, *Accident Analysis and Prevention*, 39(2): 238-251.

Marshall, W.E.; Garrick, N.W. 2011. Evidence on Why Bike-Friendly Cities Are Safer for All Road Users, *Environmental Practice*, 13(1): 16-27.

Menghini, G.; Carrasco, N.; Schüssler, N.; Axhausen, K.W. 2010. Route choice of cyclists in Zurich, *Transportation Research Part A*, 44(9): 754-765.

Muñoz, B.; Monzon, A.; López, E. 2016. A Transition to a cyclable city: Latent variables affecting bicycle Commuting, *Transportation Research Part A*, 84: 4-17.

Nelson, A.C.; Allen, D. 1997. If you build them, commuters will use them - Association between bicycle facilities and bicycle commuting, *Transportation Research Record*, 1578: 79-83.

Pucher, J.; Buehler, R.; Seinen, M. 2011. Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies, *Transportation Research Part A*, 45(6): 451-475.

Quddus, M. 2008. Modelling area-wide count outcomes with spatial correlation and heterogeneity. An analysis of London crash data, *Accident Analysis and Prevention*, 40(4): 1486-1497.

Räsänen, M.; Summala, H. 1998. Attention and expectation problems in bicycle–car collisions: an in-depth study, *Accident Analysis & Prevention*, 30(5): 657-666.

Sanders, R.L. 2016. We can all get along: The alignment of driver and bicyclist roadway design preferences in the San Francisco Bay Area, *Transportation Research Part A*, 91: 120-133.

Vandenbulcke, G.; Dujardin, C.; Thomas, I.; de Geus, B.; Degraeuwe, B.; Meeusen, R.; Panis, L.I. 2011. Cycle commuting in Belgium: Spatial determinants and 're-cycling' strategies, *Transportation Research Part A*, 45(2): 118-137.

Vandenbulcke, G.; Thomas, I.; Panis, L. 2014. Predicting cycling accident risk in Brussels: A spatial case–control approach, *Accident Analysis & Prevention*, 62: 341-357.

Wang, Y.; Nihan, N. 2004. Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections, *Accident Analysis and Prevention*, 36(3): 313-321.

Wegman, F.C.M.; Zhang, F.; Dijkstra, A. 2012. How to make more cycling good for road safety?, *Accident Analysis and Prevention*, 44(1): 19-29.

SESSION 14: TRANSPORT ECONOMICS, FINANCE AND PRICING

REAL OPTION ANALYSIS APPLIED TO TRANSPORT INVESTMENT PROJECTS

Fabio Pizzutilo[1], Elisabetta Venezia[2]
[1] *Dipartimento di Economia, Management e Diritto dell'impresa – Università degli studi di Bari Aldo Moro, Italy*
[2] *Dipartimento di Scienze economiche e metodi matematici – Università degli studi di Bari Aldo Moro, Italy*

Abstract: Environmental and climatic changes can dramatically affect the long run demand and usefulness of large public transport infrastructures. Migrations, desertification, heavy weather conditions, rising in the sea level, floods, etc., are natural phenomenon difficult to estimate in their extent and timing that in the long run can have a significant impact on the use of highways, harbors, bridges, dams, rails, undergrounds, airports, etc.. Decisions about transport infrastructure projects have to be taken while future developments are uncertain. In general, they are implemented over several years, during which many factors can change significantly: technological advances, political shifts, economic fluctuations and so on. Moreover, transport infrastructure investments are usually highly costly and irreversible (in that the decision to realize the infrastructure involves costs that cannot be recouped, for example a railway track or a motorway). These uncertainties make such kinds of investment highly risky. Project managers and engineers are thus forced in embedding flexibilities in the infrastructures to cope with the increasing long run uncertainty posed by environmental, economic, social and climatic changes. Hence, flexibilities in transport investment projects, if any exist, are appreciable and valuable. Anyway, the traditional large infrastructure assessment process based on the net present value (NPV) is challenged since the value of the flexibility is rarely taken into proper consideration. We here propose to assess the value of the flexibilities any large public transport infrastructure project has through a real option analysis (ROA). A real option (RO) is the possibility that the management has to modify an investment during the course of its life to cope with the on-going development of the business. Differing from a financial option, it has no legal existence but relates directly to the real assets of the investment. From a capital budgeting perspective, coupling the classical NPV analysis with ROA can enhance the public investment decision process and facilitate decision makers' job. In practice, real options are difficult to recognize and to price properly. Since the pioneering work of Myers (1977) ROA for private companies' project valuation has been largely studied from the corporate finance perspective (Trigeorgis and Mason 1987, Ingersoll and Ross 1992, Amram and Kulatilaka 1998, Aguerreve 2003, Grenadier and Malenko 2010, to cite just a few among the copious relevant literature) and taken into proper account by analysts and practitioners of the private sector. Anyway, real options seem not yet to have received the attention that they deserve in the decision process of public infrastructure investment projects, either in theory or in practice. We conclude that coupling the classical NPV analysis with ROA enhance the public investment decision process and facilitate decision makers' job.

Keywords: transport infrastructures, financial analysis, investment decisions.

1. Introduction

Environmental and climatic changes can dramatically affect the long run demand and usefulness of large public transport infrastructures. Migrations, desertification, heavy weather conditions, rising in the sea level, floods, etc., are natural phenomenon difficult to estimate in their extent and timing that in the long run can have a significant impact on the use of highways, harbors, bridges, dams, rails, undergrounds, airports, etc.. Decisions about transport infrastructure projects have to be taken while future developments are uncertain. In general, they are implemented over several years, during which many factors can change significantly: technological advances, political shifts, economic fluctuations and so on. Moreover, transport infrastructure investments are usually highly costly and irreversible (in that the decision to realize the infrastructure involves costs that cannot be recouped, for example a railway track or a motorway). These uncertainties make such kinds of investment highly risky. Project managers and engineers are thus forced in embedding flexibilities in the infrastructures to cope with the increasing long run uncertainty posed by environmental, economic, social and climatic changes. Hence, flexibilities in transport investment projects, if any exist, are appreciable and valuable.

Anyway, the traditional large infrastructure assessment process based on the net present value (NPV) is challenged since the value of the flexibility is rarely taken into proper consideration. We here propose to assess the value of the flexibilities any large public transport infrastructure project has through a real option analysis (ROA). A real option (RO) is the possibility that the management has to modify an investment during the course of its life to cope with the on-going development of the business. Differing from a financial option, it has no legal existence but relates directly to the real assets of the investment. From a capital budgeting perspective, coupling the classical NPV analysis with ROA can enhance the public investment decision process and facilitate decision makers' job. In practice, real options are difficult to recognize and to price properly.

Since the pioneering work of Myers (1977) ROA for private companies' project valuation has been largely studied from the corporate finance perspective (Trigeorgis and Mason 1987, Ingersoll and Ross 1992, Amram and Kulatilaka 1998, Aguerreve 2003, Grenadier and Malenko 2010, to cite just a few among the copious relevant literature) and taken into proper account by analysts and practitioners of the private sector. Anyway, real options seem not yet to have received the attention that they deserve in the decision process of public infrastructure investment projects, either in theory or in practice.

[1] Corresponding author: fabio.pizzutilo@uniba.it

Brand et al. (2000) were among the very first to propose the incorporation of option analysis into the risk management of large public investment planning. Kitabatake (2002) presented an illustrative application study in which real options are employed to evaluate a road construction project. Smit (2003) analysed European airports expansion through a combination of real options theory and game theory. He argued that airports with infrastructures that are less constrained by growth regulations capture more value, because they are in a better position to exercise growth options available in the airport industry. Law, Mackay and Nolan (2004) used the real option analysis to re-examine a case of rail track abandonment in Canada. They concluded that the information incorporated when using real options for a rail-line abandonment decision makes the decision process less controversial. Zhao et al. (2004) presented a multistage stochastic model that incorporates real options for decision making in highway development, operation, expansion, and rehabilitation. Their model accounts for three major sources of uncertainties: traffic demand, land price, and highway deterioration. Van Bentem et al. (2006) proposed an option based model to calculate the value and optimal timing for the introduction of hydrogen as transport fuel for vehicles in large industrial areas. They treat the project as an option to postpone the investment. Kruger (2012) measured the value of the expansion option of an existing two-lane road in Sweden and examined how ownership in a public-private partnership affects the timing of expansion. Rakic, B., Rađenović, T., (2014) employed the binominal option pricing model and the risk-neutral probability approach to price the abandonment options implied in a Build-Operate-Transfer toll road investment. They argued that real options of abandon increase the value of the project. Recently, Power et al. (2015) proposed a model to value options to delay irreversible investments in infrastructure projects. Their model allowed for the stochastic evolution of financial, economic and physical variables and employed the Longstaff – Schwartz least squares Monte Carlo approach to determine the value of an American-style real option for an infrastructure investment and the optimal timing of its exercise. They argued that real-option value for infrastructure investment is substantial.

The pros and cons of implementing a real option analysis for the evaluation of public investment projects are here discussed. We conclude that coupling the classical NPV analysis with ROA enhance the public investment decision process and facilitate decision makers' job. At best of our knowledge this is among the very first studies on the subject, thus making a relevant contribution to the existent literature.

In these pages, it is assumed that the reader is familiar with basic option terminology. Among the countless books on the subject, anyone who is not used to option theory can refer to Hull (2014).

The paper is organised as follows. Next section introduces real option from a theoretical perspective. Section 3 points out and discusses advantages and drawbacks of the implementation of a real option analysis for the evaluation of public transport infrastructure projects.

2. Real options. A theoretical background

The possibility that the management has to modify an investment during the course of its life is called real option. They are options because they give the possibility to exercise flexibility if it is useful (the management is not obliged to modify the project if it is not believed to be worthwhile). They are real because their underlying is a real asset and not a financial one as for common financial options.[3]

The financial literature recognizes four main types of real options: growth (the possibility to make a follow-on investment); delay (any flexibility regarding the timing of the investment); switch (any possibility to make substantial changes to ongoing operations); abandon (it consists of all the possibilities to abandon -totally, partially or temporarily - an ongoing investment).

Growth options are any options that an investment has to expand its operations. They can be viewed as call options on the expansion project, in which the higher costs to achieve such flexibility are the premium of the option, the cost to expand is the exercise price and the maturity is the time in which it is possible to expand. With reference to public infrastructure projects, for example, consider the case of the construction of a new commercial harbour in a developing industrial area. If there is a high degree of uncertainty about the actual attraction of the new infrastructure, it can be wise to analyse the possibility to build rather than, for instance, a four-docks harbour, a two-docks one that is already arranged with the intention to become a four-docks in the future, once, given the actual use of the two-docks harbour, the demand can be assessed more exactly. The cost for the arrangement of the two-docks harbour into a four-docks one (consider, among others, the higher design expenses, the higher cost of building the harbour where there is enough space for a four-docks one, etc.) is the premium that the community has to pay in order not to incur immediately in the higher expenses (and risks) of a four-docks harbour but to have the flexibility to expand the harbour more easily and cheaply if actually needed.[4] It should be obvious that the value of the real option embedded in the two-docks harbour is higher the greater is the uncertainty regarding the actual demand for the harbour and its benefits for the community.

The option to delay consists in any flexibility regarding the timing of the investment to be started. The possibility of deferring an investment provides two main advantages. First of all, the extended time can be usefully employed for in-depth technical, operative, marketing and financial analysis, and so on, aimed at optimizing the planning of the investment and reducing the uncertainty about its costs, revenues and other benefits. Moreover, it gives the chance to choose the best moment to invest (that is the investment can be postponed to when its value is maximized). On the other

[3] For a comprehensive analysis of real option theory and practice, see among others Schwartz and Trigeorgis (2004), Mun (2005), Guthrie (2009).

[4] Notice that if the two-docks road is not arranged to become a four-docks one, the eventual future choice to expand will involve higher costs and a longer time or, in the worst case, will no longer be possible.

hand, if an investment is deferred, there is the possibility that other operators will enter the business, spoiling the expected source of value. Given these considerations, real options to delay are particularly valuable for very-long-horizon investments that cannot (or can only with difficulty) be spoilt by the concurrence (in the private sector think of the exploitation of a mine or an oilfield for which the rights have already been achieved). For these reasons, they are particularly valuable and attractive in public infrastructure investments, which by definition are very-long-term investments that do not face relevant concurrence problems (consider the possibility of deferring the above mentioned harbour project to the moment when facilities essential for its optimal exploitation – like an adequate motorway and railway system - are completed and available). From a financial perspective, real options to delay can be read as call options (in general of the American style) on a project (the underlying asset). The strike price is the amount to be spent to realize the investment (note that there could be uncertainty concerning this value too – think about technological development that could reduce some fixed costs – which adds more value to the option). The premium is the amount that is possibly paid to have the option to wait and see (consider patent rights, concession rights or, to stay in the harbour case, the cost of land expropriation or zoning the area to be used when it is actually beneficial). On the other hand, deferring the project means losing the net benefits that would have been derived from undertaking it immediately. Thus, the option to delay has to be exercised (that is, the investment has to be made) when its value is lower than the net benefits that would otherwise have been achieved.[5] Notice that in the classical DCF framework the investment can be made either now or never. The postponed investment has to be treated as an alternative investment. More efficaciously, ROA analysis advises postponing the investment if the value of the option to delay is higher than the NPV of the project realized immediately, even if the latter is highly positive. Moreover, ROA assumes that an investment cannot always be unattractive. Circumstances can change, so an investment that has a negative NPV if realized today can be attractive for the future.

Switch option refers to any flexibility that the project has to make substantial changes to its inputs and/or outputs. To remain in the harbour project, think of arranging one of the docks so that it can be easily and cheaply converted in a navy one, if the demand for a commercial use of the harbour does not get off the ground. The major costs for such an arrangement are the premium that the community has to pay to achieve such flexibility, which can be useful in countries which have the need to relocate navy operations (for example countries where navy harbours are located very close to congested cities). The financial replication of this kind of real option largely depends on the actual type of switching flexibility that the project has.

Any flexibility for the project to be ceased totally and/or partially and/or temporarily during the course of its life is called option to abandon. Given their similarity and the scope of this paper, to save space and avoid redundancies, in this category we include what should properly be named respectively as the real option to cease (total abandonment), the real option to contract activity (partial abandonment) and the real option to suspend (temporary abandonment). Almost every investment project has the possibility of being halted, contracted or suspended at any moment in time if the business fails. The numerous public infrastructures that have been abandoned or significantly downsized throughout the world bear witness that this kind of option is largely exercised by public agencies too. The value of such a real option largely depends on the value that can be recovered by the eventual total or partial abandonment and from savings in the costs to suffer to cease the activity (totally or partially) or to suspend it and eventually reactivate it (think for instance to the costs to abandon or suspend a nuclear power stations, an asbestos production, a pipelines, etc.). Hence, it could be of great importance in the planning phase of the investment to try to maximize the value of the abandonment real options embedded in the project and not to treat them as a passive event that unluckily can affect the business. For instance, to cope with an eventual seasonality of the demand for the harbour services, the infrastructure can be planned and built so that the costs for a seasonal closing and re-opening of a dock are minimized. The higher costs to be paid to realize in such a manner the harbour are the premium to achieve the flexibility to abandon temporary one dock. The higher the uncertainty about the actual seasonality of the demand for the harbour services the higher the value of this kind of real option. In their easiest forms, real options to abandon can be viewed as put options on the investment. For the ceasing and contracting real options the strike price is the net recovery price. The value of the suspended operations less the suspension costs is the strike price in the case of temporary abandonment. Abandonment real options should be exercised if the value of continuing the business is lower than the strike price.

Real options are often difficult to identify. Moreover, their valuation is more complicated than financial options given that, above others, their underlying is not traded, they can be exercised at different times and the volatility of their returns is a great exercise of estimation. Furthermore, complex investment projects can embed several real options that cannot be valued separately if, as is often the case, they are interdependent and/or conditional (think of a project that has the flexibility both to be halted and to be contracted: if halted, the contracting real options have no further value). Given these complexities, the classical Black and Scholes (1973) formula is rarely deemed to be the best way to approach real option valuation. The flexibility and simplifications allowed by binomial option pricing models (first proposed by Cox, Ross and Rubinstein, 1979), compound option pricing models (Geske, 1979, was among the very first to deal with the valuation of these kinds of options, which can apply to a large series of project flexibilities) and Monte Carlo simulations (Boyle, 1977, was among the very first to apply this class of non-parametric models to the pricing of financial options) have often been considered to be more suitable tools to value real options. Of course, the actual

[5] Those who are accustomed to financial option valuation will immediately note the similarity to an American call option on a stock that pays dividends.

preferred model is a matter of the real option to be valued, its financial and real features and the possible interactions and interdependencies with other flexibilities that the investment project has.
Anyway, the variables on which the value of a real option depends are the same as those of financial options:
a) The strike price (that is, the price at which the option can be exercised). For call options like the growth ones, the lower the strike price, the higher the value of the real option. For put options, like abandonment ones, the lower it is, the lower is the value of the real option.
b) The value of the underlying (that is, the value of the investment project). All other things being equal, it is evident that the higher the value of the project, the higher the value of the real call options written on it (like growth options) and the lower the value of the put real options (like abandonment ones).
c) The volatility of the value of the underlying (that is, the riskiness of the project). The greater is the uncertainty surrounding the project, the higher is the value of the flexibilities that the project has. Thus, the riskier the project is, the higher the value of the embedded real options is, whatever their typology.
d) The maturity (that is, the time until which they can be exercised). It should be obvious that the longer the time until any flexibility of the project can be exploited, the higher its value, regardless of whether the real options embedded in the project are to grow, to delay, to switch or to abandon.
e) The risk-free interest rate. All other conditions being equal, a change in the risk-free interest rate produces an effect of the opposite sign on the value of real put options and of the same sign on the value of real call options. Therefore, it is to be expected that an increase (decrease) in the risk-free rate results in a decrease (increase) of the value of the abandonment real option and in an increase (decrease) of the value of the growth real option.
f) Any cash flow paid by the underlying. If a project distributes the cash flows that it generates, its value reduces by the same amount. Thus, for b) above, the value of a put real option increases and the value of a call real option decreases. All other things being equal, it is better to exercise the option to abandon a project after having collected the cash flows that it can distribute than otherwise. On the other hand, not to grow or to delay an investment means losing the cash flows that the new project would have generated.
Option pricing theory makes another very important point: there are no other variables on which the value of a real option depends.

3. Implementing a real option analysis for the evaluation of public infrastructure investments

Construction of transportation infrastructure usually brings convenience and economic development. However, construction needs cannot be fully satisfied because of the limitation of capital and other resources. Hence, the priority evaluation of transportation infrastructure projects is very necessary (Shi and Zhou 2012). As an important aspect of sustainable transportation, transportation financial analysis has gradually drawn researchers' attention. However, the usual evaluation method is the finacial NPV which ignores some of the aforementioned advantages of ROA. Although some researchers have already begun theoretical studies on transportation evaluation with regard to this aspect, practical and quantitative evaluation methods are still in need.
Although some public infrastructure projects are reported to be realized with the declared intention of having valuable future flexibility, a formal real option analysis is not a usual part of the evaluation process of public transport investments yet.[6] Nevertheless, the advantages that can derive from the use of ROA in public infrastructure investment decisions are manifold.
First of all it has to be considered that the traditional discounted cash flow (DCF) analysis values an investment project with reference to the cash flows that the project is anticipated to produce in the expected scenario. It implicitly assumes that managers are passive in the ongoing operations of the investment once it has been implemented and that they will adhere strictly to the planned strategy, without any possibility to adjust it if needed or valuable. Thus, DCF analysis fails to capture the value of the flexibility, if any, that the management has to adapt or modify the project during its life in response to unexpected internal and external developments, resulting in an undervaluation of the investment.
Another important advantage of employing a real option analysis is that thinking and managing in the light of real options permits the elaboration of a decision tree, a plan in which are drawn the lines for future important actions that allow the exploitation of the flexibilities in the investment. Decision trees enable the provision of rules about if and when to exercise real options and allow the flexibility of the investment to be managed strategically. Moreover, they reduce the conflicts among the executives of the project and improve their ability to react to sudden changes in the business or to important new information since the lines for future strategic actions have already been traced. It also allows more effective control of the variable on which the profitability and the risk of the investment depend and provides the possibility to step in cheaply and in a timely manner to take advantage of the upside volatility of the project or to minimize the downside risk.
Moreover it has also to be taken into consideration that ROA is a complementary analysis to the classical DCF not an alternative one. The actual value of a project is the classical NPV plus the value of the flexibilities. Consider two

[6] Gesner and Jardim (1998) evidenced that for the construction of the Tagus River bridge in Portugal, in 1966, a stronger structure was employed to permit easier enlargement (eventually, in 1993, the bridge was doubled to cope with the traffic increase). Herder et al. (2011) reported that for the construction of Maasvlakte 2, a large-scale expansion of the Port of Rotterdam, the Port Authority chose a phased construction to have the flexibility to abandon the following phase of the project if the market deteriorated.

investments A and B that have the same positive NPV and are identical in all but one point: at any moment during its life, project B can be abandoned at a recovery price P whilst project A cannot. Any rational investor will prefer project B to project A. Thus, project B is worth more than project A. The difference in values is the value of the flexibility that project B has to abandon the operations at any time if they break down. If the uncertainty about the future prospects of the projects is null, there will certainly not be a need to abandon project B. Thus, the value of its flexibility is null and both A and B are preferable. The greater the uncertainty about the future prospects of the projects, the greater the possibility that the management will exercise the exit plan of project B. Real options are worth more the more uncertain the expected scenario is. ROA is thus needed more when the level of uncertainty is high, as it is in many transport investment projects in modern times. NPV fails in considering the value of the flexibility.
Another important advantage can be viewed in the fact that public investments often suffer from inertia in their management. A real option approach instead prompts public executives to manage the project in a proactive way. They are forced to recognize that projects are composed of managerial options and to develop more structured thinking to identify, value, create and manage them adequately.
Last but not least, it has to be considered that a usual drawback of public transport investment is their overbuilding, that is, the fact that they are often built to serve a greater demand than actually exists. An RO approach induces public decision makers and executives of the project to create and preserve flexibility to modify the investment according to the future developments and avoid useless overcapacity.

4. Conclusion

There are some limitations in the use of ROA of which the decision maker has to be aware. The difficulties in correctly evaluating real options are clearly one. Optimistic estimates of variables like the recovery price, volatility, future cash flows and so on or the improper consideration of the interactions between all the real options embedded in the project can lead to excessive evaluations and thus the justification for useless investments. Moreover, the subjectivities implicit in such estimates lead to not negligible conflict of interests between the commonality, the tax payers and the end-users on one side and the private or political interests in the execution (or in the lack of execution) of the work or of the real option on the other. It also has to be taken into consideration that the difficulties inherent in the valuation of the real options can impact negatively on the level of transparency of the public decisional process.
Other limitations come from the fact that adopting a real option investment decision approach requires the skills and capacity to monitor and review the project before and after its implementation. This means investing in human and technological resources. While large public bodies can afford these costs, minor ones cannot. Moreover, especially for small public investments, the costs and the time involved in such an analysis can be excessive, thereby limiting the efficacy of the option valuation process.
The third limitation stems from the public infrastructure investment regulation. As long as it does not explicitly allow for ROA, either in the evaluation phase or in the accounting, managing and financing phases, there could be serious disincentives for its implementation.
The experts focus on the problems of financial analysis and effectiveness estimation of individual investment projects or an assembly of independent projects. Formation and analysis of the investment programs do not have a proper attention. To solve these problems, special methodologies, models, methods, and supporting instrumental facilities must be developed and implemented. Therefore, the transport investment project must be regarded as a complicated large-scale investment project, which would enable one to make use of the procedures and tools developed for financial analysis and effectiveness estimation of the investment projects. Introduction of the proposed methodology into the practice of transport investment project would appreciably improve financial feasibility analysis of infrastrucutral projects, essentially increase validity, quality, and efficiency of the managerial decisions, coordinate the results of planning, and substantially reduce their laboriousness.

Acknowledgements

Results presented in this paper are part of the research projects “Il processo decisionale nella scelta degli investimenti: aspetti economici, geografici, finanziari e traduttivi” and “Etica ed equità: una ricerca su percorsi economici, finanziari e territoriali” both supported by the University of Bari Aldo Moro.

References

Aguerrevere, F.L. 2003. Equilibrium Investment Strategies and Output Price Behavior: A Real-Options Approach, *Review of Financial Studies*, 16: 1239-1272.
Amram, M.; Kulatilaka, N. 1998. Real Options Managing Strategic Investment in an Uncertain World, Harvard Business School Press, Boston.
Black, F.; Scholes, M. 1973. The Pricing Options and Corporate Liabilities, *Journal of Political Economy*, 81(3): 637-654.
Boyle, P.P. 1977. Options: A Monte Carlo Approach, *Journal of Financial Economics*, 4(3): 323-338.
Brand, D.; Mehndiratta, S.; Parody, T. 2000. The options approach to risk analysis in transportation planning, *Transportation Research Record*, 1706: 54-63.

Cox, J.C.; Ross, S.A.; Rubinstein, M. 1979. Option pricing: A simplified approach, *Journal of Financial Economics*, 7(3): 229-263.

Geske, R. 1979. The valuation of compound options, *Journal of Financial Economics*, 7(1): 63-81.

Gesner, G.; Jardim, J. 1998. Bridge within a bridge, *Civil Engineering*, 68: 44-47.

Grenadier, S.R.; Malenko, A. 2010. A Bayesian Approach to Real Options: The Case of Distinguishing between Temporary and Permanent Shocks, *The journal of Finance*, 65(5): 1949-1986.

Guthrie, G. 2009. *Real Options in Theory and Practice*, Oxford University Press, Oxford.

Herder, P.M.; de Joode, J.; Ligtvoet, A.; Schenk, S.; Taneja, P. 2011. Buying real options – Valuing uncertainty in infrastructure planning, *Futures*, 43(9): 961-969.

Hull, C.J. 2014. *Options, Futures, and Other Derivative*, 9th Editions, Prentice Hall.

Ingersoll, J .E.; Ross, S.A. 1992. Waiting to Invest: Investment and Uncertainty, *Journal of Business*, 65(1): 1-30.

Kitabatake, Y. 2002. Real options analysis of the Minami Alps forest road construction project: new valuation approach to social infrastructure project with sequential unit projects, *Environmental Economics and Policy Studies*, 5(4): 261-290.

Krüger, N.A. 2012. To kill a real option – Incomplete contracts, real options and PPP, *Transportation Research Part A*, 46(8): 1359-1371.

Lara Galera, A.L.; Sanchez Solino, A. 2010. A Real Options Approach for the Valuation of Highway Concessions, *Transportation Sciences*, 44(3): 416-427.

Law, S.M.; Mackay, A.E.; Nolan, J.F. 2004. Rail infrastructure management policy: Applying a real options methodology, *Public works management & policy*, 9(2): 1-9.

Mun, J. 2005. *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions*, 2nd Edition, John Wiley & Sons Inc., Hoboken, NJ.

Myers, S.C. 1977. Determinants of Corporate Borrowing, *Journal of Financial Economics*, 5(2): 147-175.

Power, G.P.; Tandja, M.C.D.; Bastien, J.; Grégoire, P. 2015. Measuring infrastructure investment option value, *The Journal of Risk Finance*, 16(1): 49-72.

Rakic, B.; Rađenović, T. 2014. Real Options Methodology in Public-Private Partnership Project Valuation, *Economic Annals*, 59(200): 91-113.

Schwartz, E.S.; Trigeorgis, L. 2004. *Real Options and investment under uncertainty*, The MIT press, Cambridge, MA, USA.

Shi, J.; Zhou, N. 2012. A quantitative transportation project investment evaluation approach with both equity and efficiency aspects, *Research in Transportation Economics*, 36: 93-100.

Smit, H.T.J. 2003. Infrastructure Investment as a Real Options Game: The Case of European Airport Expansion, *Financial Management*, 32(4): 27-57.

Trigeorgis, L.; Mason, S.P. 1987. Valuing Managerial Flexibility, *Midland Corporate Finance Journal*, 5(1): 14-21.

Van Benthema, A.A.; Kramera, G.J.; Ramer, R. 2006. An options approach to investment in a hydrogen infrastructure, *Energy Policy*, 34(17): 2949-2963.

Zhao, T.; Sundararajan, S.K.; Tseng, C. 2004. Highway Development Decision-Making under Uncertainty: A Real Options Approach, *Journal of Infrastructure Systems*, 10(1): 23-32.

ECONOMIC IMPACT OF TRANSPORT INFRASTRUCTURE INVESTMENT

Marko Miljković[1], Jelica Petrović Vujačić[2]
[1,2] University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, Belgrade, Serbia

Abstract: Transport infrastructure investment covers spending on new transport construction, as well as on the improvement of the existing network. It provides a number of benefits for the entire economy, including positive impact on availability of goods and services, volume of trade, productivity of the economy, employment and level of business activity, transport costs and possibility of achieving economies of scale, value of assets, balanced regional and local economic development etc. The paper analyses economic impact of transport infrastructure investment, with special focus on positive contribution to economic growth measured by growth rate of gross domestic product in real terms. There can be identified various channels of such an impact. Transport infrastructure investment can lower costs and raise competitiveness of products, which stimulates the production and contributes to economic growth, but also opens the door to greater savings and investments. Investment in transport infrastructure, also affects aggregate demand level by stimulating the construction industry, as well as a series of related branches of manufacturing industry, whose inputs are used in the construction industry. In addition, investment in transport infrastructure provides positive signals to key sectors of the economy. The conducted empirical researches on the impact of transport infrastructure investments, which mostly rely on Cobb–Douglas production function approach, confirm literature findings on positive impact on economic growth, whether the researches were based on multi-country panel data analysis or on single-country time series analysis. The paper also considers the economic impact of transport infrastructure investment from the point of importance of possible crowding-out effect, which indicates that higher public spending, financed primarily from loans, increases aggregate demand and interest rate and thus reduces the level of private investments.

Keywords: transport infrastructure investment, economic impact, economic growth.

1. Introduction

Economic thought has been interested in transport infrastructure investment and its effects on the entire economy, especially on economic growth and development since the time of Adam Smith at the end of 18th century. At the beginning, the issue of justification of state involvement in transport infrastructure financing was mainly addressed by the literature, considering the fact that transport infrastructure possesses some characteristics of public goods. Namely, transport infrastructure is a non-rivalrous good, considering that use of one individual does not reduce availability to others. Furthermore, there are often high costs, or even no possibility of exclusion of users which do not want to pay for use of infrastructure, which causes a free-rider problem. Because of these characteristics, transport infrastructure can be supplied at an optimal level only by public funding, while private sector funding would cause a supply at a suboptimal level (Banister & Berechman, 2000).

Also, the literature from the end of 20th century discussed an importance of crowding-out effect in the case of public engagement on transport infrastructure investment. While Rietveld (1989) and Morrison & Schwartz (1996) indicate that higher public investment in transport infrastructure, financed mainly by borrowing, increase aggregate demand and interest rate and thereby impact on reduction of private sector investment, Aschauer (1991) and researches of World Bank (World Bank, 1996) deny the existence of crowding-out effect in this case and emphasize that development of transport infrastructure significantly decreases operating costs and thereby increase rates of return of private sector investment which actually stipulates investment.

Traditional government funding sources are surely insufficient to meet the increasingly complex and diverse needs of the transportation system. Therefore, a range of innovative financing solutions to support sustainable development have emerged in recent years, including new financial instruments, investment funds and financing approaches (Petrović Vujačić, 2014).

Economic impact of transport infrastructure investment are numerous and they include positive impact on availability of goods and services, volume of trade, productivity of the economy, employment and level of business activity, transport costs and possibility of achieving economies of scale, value of assets, etc. Nowadays, economic literature pays most attention to positive contributions of transport infrastructure investments to economic growth and development, which is actually a main focus of this paper.

At the very beginning of the paper, there are presented transport infrastructure investment and maintenance spending in OECD countries during the last fifteen years, in order to analyse the values, structure and main developments in this field. Preconditions for successful impact on economic growth, as well as channels of such an impact are explained in the third chapter of the paper. Finally, in the fourth chapter there are presented important findings of relevant empirical researches from the last decade.

2. Transport infrastructure investment and maintenance spending

It is important to make a difference between transport infrastructure investment and maintenance spending, considering quite high amounts of maintenance spending nowadays, especially in developed countries with high per capita income

[1] Corresponding author: m.miljkovic@sf.bg.ac.rs

and well developed infrastructure network. According to definition of OECD, transport infrastructure investment covers spending on new transport construction and the improvement of the existing network which increases its performance or capacity, while maintenance spending does not change performance and capacity of infrastructure (OECD, 2013).
Total values of transport infrastructure investment by European countries are presented in Table 1. The countries are selected according to availability of data for the period of last fifteen years and include Albania, Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Latvia, Lithuania, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Turkey and United Kingdom. The presented data were collected by the International Transport Forum from transport ministries, statistical offices and other public institutions.
The aggregate values of investment in the last fifteen years strongly depend on the size of the country and its development level. Therefore, the highest values were recorded in France, Germany, Spain and United Kingdom, while the lowest values within the sample are associated with Albania, Serbia, Latvia, Lithuania, Slovenia and Slovakia. The first conclusion from presented data indicate positive developments during the period 2005-2009. Aggregate value of investment in this period was in almost each country higher than in the previous five-year period, with non-weighted average growth rate of 92% in nominal terms, i.e. 52% in real terms (with excluded inflation impact). Latvia, Albania, Romania and Czech Republic more than doubled the level of transport infrastructure investments, while Germany experienced a slight decrease in the level of investment. On the other hand, investment has significantly slowed down during the period 2010-2014, with non-weighted average growth rate of only 5% in nominal terms as compared with the previous five-year period, while the growth rate in real terms was even negative and amounted to -10%. Only Nordic countries, as well as Turkey, experiences positive growth rates during this period.

Table 1
Aggregate values and growth rates of transport infrastructure investments by selected European countries in the period 2000-2014

Country	Aggregate value, EUR million, current prices			Growth rate, as compared with previous five-year period			
				In nominal terms, %		In real terms, %	
	2000-2004	2005-2009	2010-2014	2005-2009	2010-2014	2005-2009	2010-2014
Albania	502	1,523	1,089	203	-28	162	-36
Austria	9,635	13,285	11,030	38	-17	25	-25
Belgium	7,801	8,623	9,766	11	13	-1	2
Czech Republic	5,232	12,875	7,696	146	-40	118	-46
Denmark	5,484	6,802	10,314	24	52	13	36
Finland	4,589	6,624	8,261	44	25	34	11
France	75,246	91,406	105,874	21	16	10	7
Germany	100,455	87,531	93,223	-13	7	-20	-2
Latvia	448	1,772	1,476	296	-17	188	-29
Lithuania	951	2,221	2,479	134	12	95	-5
Romania	4,930	15,911	17,258	223	8	100	-13
Serbia	709	1,706	1,594	140	-7	53	-36
Slovakia	1,816	3,735	3,522	106	-6	65	-15
Slovenia	2,123	3,204	1,498	51	-53	26	-58
Spain	62,154	103,262	66,223	66	-36	44	-42
Sweden	10,758	14,160	17,504	32	24	21	14
Turkey	6,143	14,421	35,364	135	145	5	74
United Kingdom	68,106	69,202	63,732	2	-8	-8	-21

Source: OECD Statistics Database

Further consideration of structure of transport infrastructure investment indicates that the highest share in total transport infrastructure investment refers to road and rail infrastructure investment, which amounts to at least 80%, but often even more than 95%. In most countries, the dominant share refers to road investment, except in Austria and Belgium, which invested more than 60% of total transport infrastructure investment in rail infrastructure. Share of road and rail infrastructure investment in total transport infrastructure investments are presented in more details in Table 2.

Table 2
Share of road and rail infrastructure investment in total transport infrastructure investments by selected European countries in the period 2000-2014

Country	Share of road investment			Share of rail investment		
	2000-2004	2005-2009	2010-2014	2000-2004	2005-2009	2010-2014
Albania	86.0%	97.4%	97.3%	2.4%	0.4%	0.3%
Austria	31.3%	29.3%	16.6%	61.7%	60.7%	81.4%
Belgium	10.4%	9.5%	22.0%	62.2%	62.4%	56.3%
Czech Republic	53.3%	65.5%	66.8%	39.5%	27.3%	28.3%

Denmark	48.6%	70.5%	52.9%	39.8%	20.3%	42.0%
Finland	57.7%	59.5%	63.8%	27.6%	21.3%	29.5%
France	70.2%	67.0%	55.4%	20.9%	25.2%	37.9%
Germany	55.9%	63.8%	61.8%	31.7%	21.1%	21.9%
Latvia	28.2%	52.6%	63.0%	28.5%	12.7%	29.8%
Lithuania	59.8%	72.3%	59.9%	26.9%	15.6%	30.9%
Romania	77.1%	82.2%	83.7%	7.4%	6.4%	5.4%
Serbia	88.8%	91.6%	90.4%	3.1%	1.1%	2.7%
Slovakia	62.7%	67.5%	56.6%	35.5%	28.4%	39.1%
Slovenia	92.3%	87.0%	45.3%	6.2%	8.9%	49.8%
Spain	51.1%	41.7%	42.3%	25.9%	37.0%	39.8%
Sweden	56.3%	51.6%	55.2%	31.7%	42.9%	36.9%
Turkey	77.4%	69.2%	70.9%	8.8%	18.1%	22.8%
United Kingdom	40.9%	44.5%	49.2%	44.7%	51.3%	50.8%

Source: OECD Statistics Database

In Table 3 there is presented relative importance of inland waterways, maritime port and airport infrastructure investment by selected European countries in the last fifteen years.

Table 3
Share of inland waterways, maritime port and airport infrastructure investment in total transport infrastructure investments by selected European countries in the period 2000-2014

Country	**Share of inland waterways and maritime port investment**			**Share of airport investment**		
	2000-2004	**2005-2009**	**2010-2014**	**2000-2004**	**2005-2009**	**2010-2014**
Albania	8.5%	1.6%	2.4%	3.1%	0.6%	0.0%
Austria	0.2%	0.2%	0.3%	6.9%	9.7%	1.6%
Belgium	21.8%	22.0%	18.2%	5.7%	6.0%	3.4%
Czech Republic	1.1%	1.0%	1.5%	6.1%	6.2%	3.4%
Denmark	5.6%	5.5%	3.2%	6.1%	3.7%	1.8%
Finland	8.8%	13.6%	3.6%	5.9%	5.5%	3.1%
France	3.3%	3.0%	2.8%	5.6%	4.8%	3.8%
Germany	7.0%	8.7%	9.4%	5.4%	6.5%	6.8%
Latvia	33.7%	30.7%	0.0%	9.6%	4.0%	7.2%
Lithuania	12.2%	6.9%	7.6%	1.1%	5.2%	1.5%
Romania	14.8%	10.9%	10.5%	0.7%	0.5%	0.4%
Serbia	7.8%	7.2%	6.6%	0.3%	0.1%	0.3%
Slovakia	0.3%	0.1%	0.2%	1.5%	3.9%	4.0%
Slovenia	1.0%	2.4%	3.7%	0.5%	1.7%	1.3%
Spain	11.4%	12.2%	10.5%	11.5%	9.1%	7.4%
Sweden	1.6%	2.1%	2.1%	10.4%	3.4%	5.8%
Turkey	0.4%	0.7%	0.5%	13.3%	12.0%	5.8%
United Kingdom	2.7%	0.5%	0.0%	11.7%	3.8%	0.0%

Source: OECD Statistics Database

Road and rail maintenance spending values are presented in Table 4. They amounted to around one third of total road and rail investment and maintenance spending during the entire observed period.

Table 4
Road and rail maintenance spending by selected European countries in the period 2000-2014

Country	**Road and rail maintenance spending, EUR million**			**Share in total road and rail investment and maintenance spending, %**		
	2000-2004	**2005-2009**	**2010-2014**	**2000-2004**	**2005-2009**	**2010-2014**
Albania	3,867	4,100	5,072	30.2%	25.5%	31.9%
Czech Republic	2,687	4,145	4,789	35.6%	25.8%	39.5%
Finland	3,592	4,035	3,835	47.9%	43.0%	33.2%
France	16,336	29,177	32,248	19.2%	25.7%	24.6%
Latvia	369	1,207	1,192	59.2%	51.1%	46.5%
Lithuania	846	1,293	1,465	50.7%	39.8%	39.4%
Serbia	556	1,507	980	46.0%	48.8%	39.8%
Slovakia	397	803	955	18.2%	18.3%	22.1%

Slovenia	386	976	996	15.6%	24.1%	41.2%
Sweden	5,722	6,806	8,977	37.7%	33.7%	35.8%
Turkey	1,081	2,163	3,800	16.9%	14.7%	10.3%

Source: OECD Statistics Database

3. Preconditions and channels of economic impact of transport infrastructure investment

Banister & Berechman (2001) emphasized that transport infrastructure investment need a list of complementary factors in the economy in order to positively impact economic development. These preconditions include the following:

- Presence of positive economic externalities (developed labour market, buoyant local economic conditions, positive expectations etc.),
- Investment factors (availability of funds for the investment, scale, location, timing and network effects of the investment etc.),
- Political factors (supportive legal, organizational and institutional policies and processes and presence of any necessary complementary policy actions such as grants, tax breaks etc.).

As presented in the Figure 1, all these preconditions individually have little or even no impact on development. Even combines on a pair-wise basis they produce limited impact on development and growth.

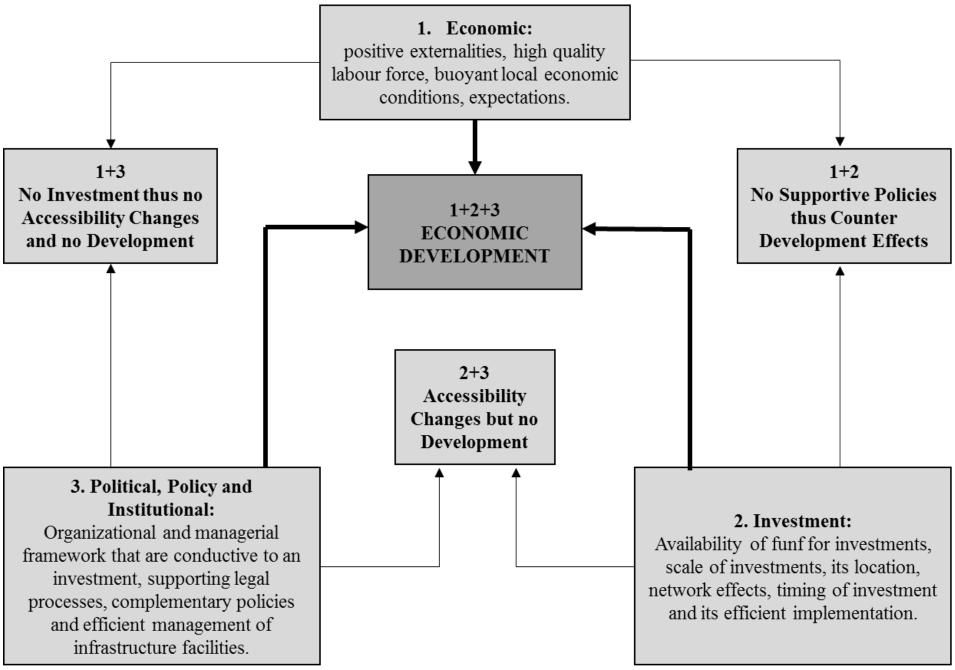


Fig. 1.
Necessary sets of conditions for economic impact of transport infrastructure investment
Source: Banister & Berechman (2001)

Banister & Berechman (2001) also developed a scheme of multi-dimension nature of the links between transport infrastructure investment, its travel effects and primary benefits, allocative externalities and at the very end economic growth. The scheme is presented in the Figure 2.

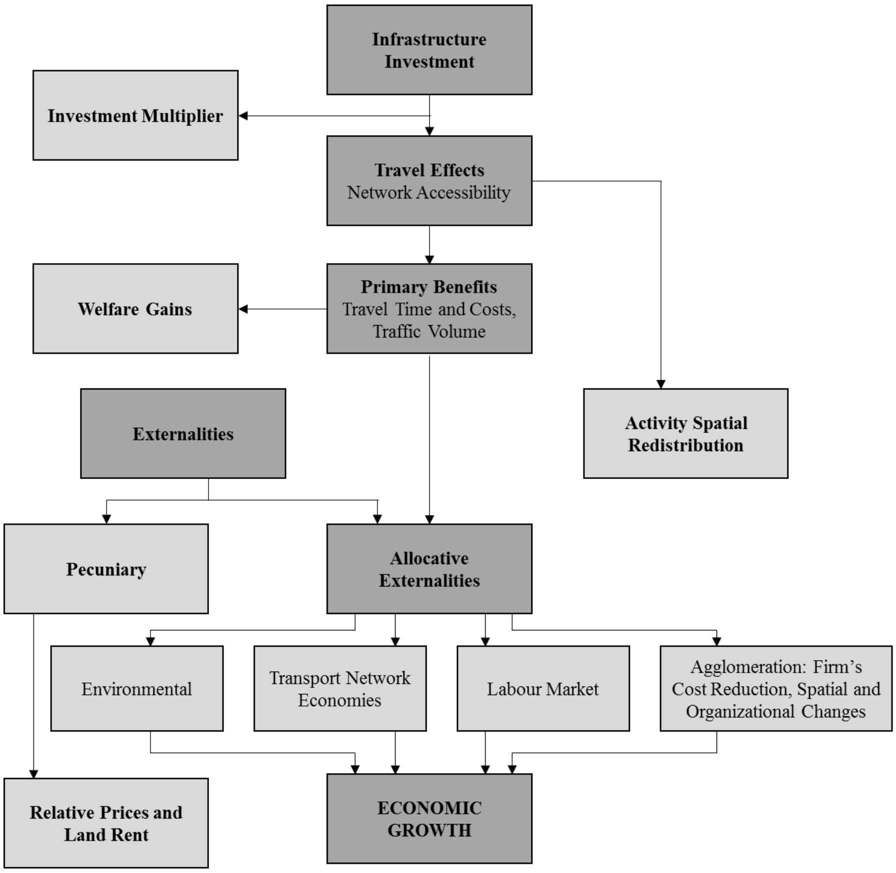


Fig. 2.
Economic growth benefits from transport infrastructure investment
Source: Banister & Berechman (2001)

There can be identified various channels of infrastructure investment impact on economic growth, as follows:

- Operating costs channel - Transport infrastructure investment can lower costs and raise competitiveness of products, which stimulates the production and contributes to economic growth, but also opens the door to greater savings and investments;
- Construction industry channel - Investment in transport infrastructure, also affects aggregate demand level by stimulating the construction industry, as well as a series of related branches of manufacturing industry, whose inputs are used in the construction industry;
- Positive signals channels - Investment in transport infrastructure provides positive signals to key sectors of the economy.

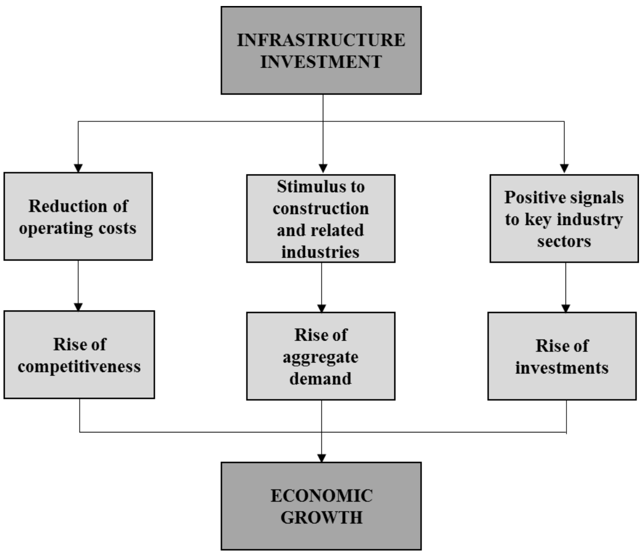


Fig. 3.
Channels of infrastructure investment impact on economic growth
Source: Authors

4. Empirical evidence of impact of transport infrastructure investment on economic growth

Most empirical researches on the nature of the links between transport infrastructure investment and economic growth rely on the production function approach. The basis for this approach is the Cobb-Douglas production function $Y=K^{\alpha}L^{\beta}$, where Y represents gross domestic product (GDP), K physical capital, and L labour input. Coefficients α and β represent output elasticity of production factors K and L and indicate sensitivity of GDP to a change in levels of factors K and L used in production. The baseline function is then modified by adding a new production factor I, representing infrastructure: $Y=K^{\alpha}L^{\beta}I^{\gamma}$, where γ coefficient stands for output elasticity of infrastructure. Econometric methods and techniques are applied usually on a log-linearized form of this function: $\ln Y=\alpha K+\beta L+\gamma I$.

Egert et al. (2009) conducted empirical research on the sample of 24 OECD member countries within the period 1960-2005. They identified a positive impact of road infrastructure investment on the level, as well as on the growth rates of GDP per capita in most countries from the sample. On the other hand, in a few countries, there was identified a negative output elasticity of road infrastructure investment, but at the same time a positive output elasticity of motorways infrastructure investment. This may reflect the fact that the road networks in these countries were very well developed and the objectives behind road infrastructure investment reflected more social considerations rather than transport routes and international connections. The same authors demonstrated also a positive impact of rail infrastructure investment on economic growth, with only few exceptions on Iberian Peninsula and Benelux countries, which may be a negative consequence of over-investment in terms of quantity, or eventually high costs associated with poor investment decisions (inadequate locations, expanding already developed networks etc.).

Del Bo & Florio (2008) carried out a research on a sample of 261 European regions defined by NUTS-2 classification within the ten-year period 1995-2005. They defined a production function of the following form: $Y=K^{\alpha}L^{\beta}H^{\delta}I^{\gamma}$, where Y represents gross domestic product adjusted with purchasing power parity, K physical capital, L labour force, and H human capital measured by percentage of labour force employed in science and percentage of highly educated employees. Variable I stands for infrastructure endowment and is consisted of 3 components: telecommunication infrastructure, soft infrastructure and hard infrastructure. Quite higher output elasticity, as well as statistical significance (at 1% level), was identified for telecommunication infrastructure and soft infrastructure measures (multi-modal potential accessibility and time-to market), 0.437 and 0.302 respectively. On the other hand, hard infrastructure indicators, such as railways, motorways and other road, do have a significantly lower elasticity of 0.045, 0.035 and -0.037 respectively at lower statistical significance level of 5% indicating that transport infrastructure is at a steady-state level in European countries. Negative output elasticity of other roads infrastructure investment is in line with findings of Egert et al. (2009).

Cantos et al. (2005) examined impact of investment in road, rail, port and airport infrastructure on economic growth and earnings in Spanish regions within the period 1965-1995. They identified an output elasticity of total transport infrastructure investment of 0.042, meaning that 10% increase of transport infrastructure investment produce 0.42% increase of GDP. Especially high impact is associated with road infrastructure investment (output elasticity 0.088), while quite lower impact can produce airport infrastructure investment (output elasticity 0.0076). The authors found that rail and port infrastructure investment had no statistically significant impact on GDP growth. An important contribution of this research is related to the conclusion that transport infrastructure investment (especially road infrastructure) increase earnings in sectors that produce nationally traded goods (agriculture and manufacturing industry), unlike sectors that produce regionally traded goods (retail and services).

Calderon (2009) researched impact of three key infrastructure sectors, including telecommunication infrastructure, road infrastructure and electric power infrastructure, on GDP per capita growth. He identified positive impact of faster accumulation of telecommunication and road infrastructure stocks on GDP growth and concluded that in African case most contribution comes from more than from better infrastructure.

Aswini at al. (2013) conducted empirical research on infrastructure investment impact on GDP growth in India. The analysis covered a ten-year period from 1999 to 2009. The authors concluded at 10% significance level that 1% increase in infrastructure investment produce 0.46% increase of GDP. Furthermore, all types of infrastructure included in the model (road construction, railways, communications, ports, storage, irrigation, electricity, gas and water infrastructure) are positively linked with GDP growth.

Almeida & Guimaraes (2014) examined whether road and energy infrastructure had any impact on income convergence among Brazilian municipalities in the period 1999-2005 and concluded that the insufficient stock of roads is a main constraint to income convergence and that road infrastructure investment could support pro-poor growth.

Melo et al. (2013) came to important conclusions carrying out a meta-analysis of 33 previously conducted researches in the period 1990-2012. They concluded that transport infrastructure investment has very stronger impact on GDP growth in long-run as compared with short and medium-run. They also identified a quite stronger impact of transport infrastructure investment on growth of agriculture and manufacturing industry, as compared with services. And finally, they found a stronger link between economic growth and transport infrastructure investment in United States than in European countries, considering that US more depends on road transportation.

A summarized conclusions of empirical researches are presented in the Table 5.

Table 5
Empirical findings on impact of transport infrastructure investment on economic growth

Authors	Sample	Time period	Main conclusions
Egert et al. (2009)	24 OECD countries	1960-2005	Positive impact of road (especially motorway) infrastructure investment on GDP growth. In developed countries, negative correlation between other road investment and GDP due to social objectives of these investments.
Del Bo & Florio (2008)	261 NUTS-2 regions of European Union	1995-2005	Positive impact of telecommunication (to a higher extent) infrastructure, as well as of motorway and rail infrastructure (to a lower extent) on GDP growth. Negative correlation between other road investment and GDP (in line with Egert et al. (2009) conclusions).
Cantos et al. (2005)	Spanish regions	1965-1995	Positive impact of road infrastructure (to a higher extent) and airport infrastructure (to a lower extent) on GDP growth. Positive impact of transport infrastructure investment on earnings in agriculture and manufacturing.
Calderon (2009)	39 African countries	1991-2005	Positive impact of faster accumulation of telecommunication and road infrastructure stocks on GDP growth. Most contribution comes from more than from better infrastructure.
Aswini et al. (2013)	India	1999-2009	Positive impact of all types of transport infrastructure on GDP growth.
Almeida & Guimaraes (2014)	Brazilian municipalities	1999-2005	Insufficient stock of roads is a main constraint to income convergence. Road infrastructure investment supports pro-poor growth.
Melo et al. (2013)	Data from 33 previously conducted researches	1990-2012	Transport infrastructure investment has stronger impact on GDP growth in long-run as compared with short and medium-run. Quite stronger impact of transport infrastructure investment on growth of agriculture and manufacturing industry, as compared with other sectors of the economy.

Source: Egert et al. (2009), Del Bo & Florio (2008), Cantos et al. (2005), Calderon (2009), Aswini et al. (2013), Almeida & Guimaraes (2014), Melo et al. (2013)

5. Concluding remarks

Economic benefits of transport infrastructure investment are numerous. The paper especially focused on analysing the impact on economic growth. There are identified various channels of infrastructure investment impact on economic growth, including operating cost channel, construction industry channel and positive signals channel. Also there are explained necessary preconditions which have to be met in order to enable a positive impact on economic growth and development, including presence of positive economic externalities, favourable investment factors, as well as political factors. The positive link between economic growth and transport infrastructure development is confirmed by summarizing the findings of recent empirical researches, especially when it comes to motorway, rail and telecommunication infrastructure. Several empirical studies proved negative link between other roads investment (except motorways) and economic growth in developed countries, considering social objectives of such investments.

References

Almeida, E.; Guimaraes, P. 2014. Economic Growth and Infrastructure in Brazil: A Spatial Multilevel Approach, European Regional Science Association Conference Paper. Available from Internet: <http://www-sre.wu.ac.at/ersa/ersaconfs/ersa14/e140826aFinal00219.pdf>.

Aschauer, A.D. 1991. Transportation spending and economic growth. Prepared for American Public Transit Association. Available from Internet: <http://www.apta.com/resources/reportsandpublications/Documents/aschauer_economic_growth_1991.pdf>.

Aswini, K.M.; Kunapareddy, N.; Bibhu, P.K. 2013. Growth and Infrastructure Investment in India: Achievements, Challenges, and Opportunities, *Economic Annals,* 58(1): 51-70.

Banister, D.; Berechman, J. 2000. Transport Investment and Economic Development. UCL Press, UK. 370 p.

Banister, D.; Berechman, J. 2001. Transport investment and the promotion of economic growth, *Journal of Transport geography*, 9(3): 209-218.

Calderon, C. 2009. Infrastructure and Growth in Africa. World Bank, Working Paper Series 4914. Available from Internet: <ftp://ftp.worldbank.org/pub/repec/SSRN/staging/4914.pdf>.

Cantos, P.; Gumbau-Albert, M.; Maudos, J. 2005. Transport infrastructures and regional growth: evidence of the Spanish case. University Library of Munich MPRA Paper No 15261. Available from Internet: <https://mpra.ub.uni-muenchen.de/15261/1/MPRA_paper_15261.pdf>.

Del Bo, C.; Florio, M. 2008. Infrastructure and growth in the European Union: an empirical analysis at the regional level in a spatial framework. Department of Economics, Management and Quantitative Methods at the University of Milan, Departmental Working Papers No. 2008-37. Available from Internet: <http://wp.demm.unimi.it/files/wp/2008/DEMM-2008_037wp.pdf>.

Egert, B.; Kozluk, T.; Sutherland, D. 2009. Infrastructure and growth: Empirical Evidence. OECD Economics Department Working Papers No. 685. Available from Internet: <www.cesifo-group.de/portal/page/portal/DocBase_Content/WP/WP-CESifo_Working_Papers/wp-cesifo-2009/wp-cesifo-2009-07/cesifo1_wp2700.pdf>.

Melo, P.C.; Graham, D.J.; Brage-Ardao, R. 2013. The productivity of transport infrastructure investment: A meta-analysis of empirical evidence, *Regional Science and Urban Economics*, 43(5): 695-706.

Morrison, C.J.; Schwartz, A.E. 1996. State infrastructure and productive performance, *American Economic Review*, 86(5): 1095-1111.

Petrović Vujačić, J. 2014. Innovative Financing of Transport Infrastructure and Economic Growth. In *Proceedings of the Second International Conference on Traffic and Transport Engineering (ICTTE)*, 575-582.

Rietveld, P. 1989. Infrastructure and regional development, *Annals of Regional Science*, 23(2): 255-274.

OECD Statistics Database. Available from Internet: <http://stats.oecd.org/>.

World Bank. 1996. Sustainable Transport, Priorities for Policy Reform. Available from Internet: <http://www.worldbank.org/transport/transportresults/documents/sustain-transp-1996.pdf>.

BENCHMARKING OF COMPANIES DEALING WITH TRANSPORT INFRASTRUCTURE IN TERMS OF THEIR PERFORMANCE

Tatiana Semenova[1], Eva Ondrušková[2], Eva Vítková[3]
[1,2,3] Brno University of Technology, Faculty of Civil Engineering, Department of Structural Economics and Management, Brno, Czech Republic

Abstract: Benchmarking as a method of management has had a new meaning in business. The aim of benchmarking is assessing the efficiency of the company in comparison to other organizations on both the domestic and international market. Lessons learned from other companies can be used for establishing improvement in the targets and for promotion changes in the organisation. This paper describes the scope of these initiatives and discusses the lessons learned and improvement of the opportunities that have been identified in the organizational structure as well as the method of financial management. Data collected for this article has been based on four major construction companies from the Czech Republic and Portugal which focus on realization of transport constructions. Basic parameters of benchmarking have been chosen based on the selected methods of financial analysis representing the performance of the company. Furthermore, the most successful company has been detected based on a comprehensive analysis of calculated results in the value engineering. Recommendations for improving financial situation and effectiveness of other researched companies have been set as a result of the research and analysis of practical activities of the company. In addition the development of construction companies which focuses on realization of transport constructions has been compared to the development of economy of the country for better understanding of company's position on internal market. Moreover issues dealing with application of benchmarking in practice have been discussed in the final part of the article.

Keywords: benchmarking, financial analysis, performance indicators, Czech Republic, Portugal.

1. Introduction

Current economic environment has been characterized by strong competition, increasing uncertainty and discontinuity. Increasing competition on the global market forces enterprises to increase the efficiency of internal processes in order to retain competitiveness. This issue is even more important in engineering industry suffering from the decrease in the volume of public and private tenders. Moreover current global financial situation has had major negative impact on availability of both private and public finance for civil and transport infrastructure investments.

Thus, organizations are required to bring value to their facility delivery programmes. Performance measurement and benchmarking are two tools which can assist companies in improving their status in the international industry. While the former is perhaps the most significant development for solving performance-related problems to ensure business success, the latter is essentially an integral part of planning and the ongoing process of improvement to ensure a focus on the external environment and strengthening the use of factual information in developing plans.

Transport construction is vital for well-functioning of economic activities and represents a key for ensuring social well-being and cohesion of population and thus it is important for measuring and comparing it to the best companies in order to make industry globally competitive.

However, making forecasts at the time of crisis is very difficult. In today's highly competitive world and rapidly changing global economy, every company has to know its economic situation, its business environment as well as competitors in order to promote and maintain its position on the market. Enterprises have to consider, and in many cases adopt or implement, a wide range of innovative management philosophies, approaches, tools and techniques. Benchmarking has proved to be a useful, easily understandable and effective tool for remaining competitive among improvement strategies and techniques such as Total Quality Management, Continuous Quality Improvement and Business Process Reengineering.

2. Literature review

Most of research papers focus on application of benchmarking in different industry sectors, and thus, definitions of the term "benchmarking" are not unified.

Camp (1989) wrote the first definitive book on benchmarking and defined benchmarking as "the continuous process of measuring products, services, and practices against the toughest competitors or those companies recognized as industry leaders". The Construction Industry Institute (CII) has adopted the following definition of benchmarking: "A systematic process of measuring one's performance against results from recognized leaders for the purpose of determining best practices that lead to superior performance when adapted and implemented" (Hudson, 1997).

Traditional view of benchmarking required two separate disciplines focused on performance improvement: measures and methods. Identifying and capturing performance indicators (the measures) is only the first step; developing and implementing performance improvement (the methods) is the second and the most important step for the benchmarking process to be truly effective (Camp, 2006).

Performance benchmarking enables managers to assess their competitive position by product or service comparison. Numerous industries apply performance benchmarking as a standard method in relations with competitors.

[3] Corresponding author: semenovat@study.fce.vutbr.cz

In addition to this, there are numerous classifications, but the most often used is the one which differentiates between two benchmarking types: internal and external benchmarking.
Internal benchmarking implies comparison of some sectors and divisions within the organization. This benchmarking type is generally used in big, multinational companies where each company's department performs specific activity or operation. In these companies an intensive internal research in order to get an insight into business operations, department's strengths, weaknesses and operating methods of each department represents a starting point for the benchmarking project.
External benchmarking is divided into external competitive benchmarking, external industrial or functional benchmarking and external generic benchmarking. External competitive benchmarking is comparison of company's activity to direct competitors. External industrial or functional benchmarking compares company's functions to functions of other companies. External generic benchmarking broadens fields of application of benchmarking process beyond the limits of specific company and industry it belongs to (Marković, Dutina, Kovačević, 2011).
Benchmarking is a continuous learning process. For effective implementation of benchmarking it is necessary to respect the benchmarking cycle. In order to get useful results from benchmarking it is absolutely necessary to keep a systematic approach. Over time, different methodologies have been developed, so different sources describe steps of benchmarking differently. The most important is the approach developed by four organisations which are extensively involved in benchmarking (Boeing, Digital Equipment, Motorola and Xerox). This approach establishes general context for the creation of a process model and uses four phases of benchmarking - planning, data collection, analysis and improvement through adaptation (Wobbe, 2000).

3. Methodology

This research is based on the study and analysis of literature sources, original scientific research papers, studies and available materials on benchmarking. Moreover, these surveys include other sources available on the Internet. It comprises also document research as the financial statements have been used (balance sheet, profit/loss accounts and statement of cash flows) to calculate indicators of the companies studied. The collected data has been taken from the reports and accounts published by the companies creating the research sample.
The aim of the research is to investigate the concept, process and use of financial benchmarking in order to improve business efficiency by comparing the organization to the market leaders and best applying the practices to achieve competitiveness and profitability in business.
This study has used quantitative research methods using standard math tools and descriptive statistics to the respective evaluation of companies creating the sample. The quantitative and qualitative criteria have been operationalized by individual indicators in a further step to be quantified and consequently measured. Actual benchmarking has then been performed at this level of individual indicators. Methodology used specifically enabled to perform fundamental analysis and applying financial analysis of companies across the financial indicators method. Normally, the organizational performance is measured in terms of KPIs.
Since too many KPIs can be unmanageable, management has to select appropriate KPIs. According to Swan and Kyng (2004), the suitable number of KPIs should be 4-10. So in order to draw up a clear picture of a company's performance, the following six most important indicators with different types of ratios have been selected for the research: efficiency, profitability, liquidity and financial and investment leverage. The financial, economic and market data for this study has been collected from the reports and accounts. The information gathered for the performance of the analysis refers to the 2012-2014 period. Four companies with high ratings in the country, two of them from Portugal and two from the Czech Republic have been selected for the research.

3.1. Financial analysis

In practice, methods of financial analysis can be used for assessing the market position in relation to the competitors - it is benchmarking. However, understand the results as a whole is needed for assessing the overall situation of the company (Brigham, Ehrhardt, 2011).

3.1.1. Liquidity ratio

A lot about the stability of the company can be found out with the help of liquidity ratios. Liquidity can be defined as the ability to meet the obligations in time and in full scale. We distinguish three types (degrees) of liquidity that are current ratio, quick ratio and cash ratio. Current ratio and quick ratio have been chosen for the analysis.

$$\text{Current ratio} = \text{Current assets} / \text{Current liabilities} \tag{1}$$

$$\text{Quick ratio} = (\text{Current assets} - \text{Inventories}) / \text{Current liabilities} \tag{2}$$

3.1.2. Activity ratios

Using the activity ratios represent one of the important tools of business management because these ratios provide information on the relative involvement of capital invested in assets.

$$\text{Asset turnover} = \text{Sales} / \text{Total Assets} \tag{3}$$

3.1.3. Debt ratios

The analysis of the company's debt management is made using debt ratios - debt ratio and debt to equity ratio. By determining rate of debt, company can evaluate whether it can have further debt without much risk.

$$\text{Debt ratio} = \text{Liabilities} / \text{Total assets} \tag{4}$$

3.1.4. Profitability ratios

Profitability ratios are one of the most observed ratios of the company, because the basic goal of the company is primarily to maximise its profit. These ratios can measure the earning power of the company. The research focuses on the return on equity and return on assets (Nývltová, Marinič, 2010)

$$\text{Return on equity} = \text{Net Profit}/ \text{Equity} \tag{5}$$

$$\text{Return on assets} = \text{EBIT} / \text{Total assets} \tag{6}$$

4. Background of the companies

This article studies practices of four major construction companies which are focused on realisation of transport constructions and which operate actively on the global market: Metrostav, STRABAG Inc. (Czech Republic), Mota-Engil, and Teixera Duarte (Portugal).

Table 1
Overview of the case study companies

	Metrostav (CZ)	STRABAG Inc.	Mota-Engil (PT)	Teixeira Duarte
Employees (global)	2,889	1,912	14,400	13,261
Revenue	€ 1.078 billion	€ 0.399 billion	€ 2.368 billion	€ 1.629 billion
Net Income	€ 17.74 mil.	€ 3.594 mil.	€ 50.6 mil.	€ 63.9 mil.

Source: 2014 annual reports of the companies

Metrostav (CZ). Today Metrostav operates in all segments of the building industry and its activities account for almost half of domestic underground construction as Metrostav is one of the few companies in the country that employ highly specialised mining methods of construction. Traditionally, transport engineering accounted for the largest share by financial volume (almost one-third of projects), followed by civil engineering, industrial construction and projects manifesting the original focus of the company – subterranean bored structures and metro constructions.
Strabag (CZ). Strabag Inc. as a part of the European concern STRABAG SE is a leading construction company in the Czech Republic. Its portfolio of activities includes all kinds of building achievements in the sectors of transport, land and civil engineering. Transportation engineering realises about 70% of turnover of STRABAG Inc.
Mota-Engil (PT). Mota-Engil is a Portuguese Group, leader in the sectors of civil construction, public works, port operations, waste, water and logistics. The Mota-Engil Group comprises 228 companies within three major business areas – engineering and construction, environment and services and transport concessions. The transport concessions are a business area of strategic importance for the Mota-Engil Group. Resulting from its proven experience in designing, constructing and managing transport infrastructures, Mota-Engil Group, through Ascendi, has been asserting itself more and more on a national and international level.
Teixeira Duarte (PT). Having started its activity in 1921, Teixeira Duarte is now the leading number one of the largest Portuguese Economic Groups. Teixeira Duarte operates in 16 countries in 7 different sectors such as construction, transport construction, concessions and services, real estate, hotel services, distribution, energy and automobile industry. Teixeira Duarte is engaged in civil construction and public works. The company also specializes in maritime and river works and rail infrastructures. Moreover company pays big attention to environment, transport and road development.

5. Analysis and discussion of data obtained

Identifying the most successful company is important for determination of the financial health of every company and comparing it with the average for the country. Past, present and future financial performance of the company is

necessary for assessment provided by financial analysis. The main aim of financial analysis is to identify financial health, weaknesses that could lead to further problems and strengths what the company could improve. Balance Sheet, Profit/Loss account and Cash Flow are the main sources of data for financial analysis.
Financial ratios are very powerful tools for performing quick analysis of financial statements. There are four main categories of ratios: liquidity ratios, profitability ratios, activity ratios and leverage ratios. These are typically analyzed over time and across competitors in the industry. Financial analysis is needed for determination of the company status, its position on the market and if it is close to bankruptcy (Sheremet, Negashev, 2013).
Financial ratios have been identified as a result of the calculation of the basic indicators of activity of the firms. For the comparison, the financial position of companies composed of the result list and summary calculations presented also by country have been used for the correctness of the data (Tab. 2).

Table 2
Values found for the companies in the financial indicators during 2012-2014 study period

Indicator		Year		
		2012	2013	2014
Current Ratio	Mota-Engil SGPS SA	0.94	1.0	1.1
	TEIXEIRA DUARTE	0.9	0.96	1.07
	Metrostav Inc.	1.93	1.75	1.9
	STRABAG Inc.	1.83	1.73	1.64
	Czech Republic	1.66	1.53	1.42
	Portugal	1.17	1.2	1.24
Quick Ratio	Mota-Engil SGPS SA	0.67	0.72	0.89
	TEIXEIRA DUARTE	0.65	0.75	0.8
	Metrostav Inc.	1.88	1.61	1.83
	STRABAG Inc.	1.77	1.66	1.60
Asset Turnover	Mota-Engil SGPS SA	0.65	0.64	0.62
	TEIXEIRA DUARTE	0.5	0.57	0.59
	Metrostav Inc.	1.08	1.03	1.08
	STRABAG Inc.	1.23	1.30	1.24
	Czech Republic	0.88	0.83	0.81
	Portugal	0.57	0.45	0.47
Debt Ratio	Mota-Engil SGPS SA	87.88	85.18	85.41
	TEIXEIRA DUARTE	70.18	68.95	69.02
	Metrostav Inc.	63.19	66.28	61.4
	STRABAG Inc.	62.40	64.28	67.11
	Czech Republic	57.28	58.33	40.53
	Portugal	69.36	67.5	64.36
ROE	Mota-Engil SGPS SA	16.97	15.82	14.37
	TEIXEIRA DUARTE	9.52	19.69	17.95
	Metrostav Inc.	4.59	4.73	7.14
	STRABAG Inc.	5.83	12.05	3.56
	Czech Republic	6.45	5.97	5.87
	Portugal	0.0	2.8	3.1
ROA	Mota-Engil SGPS SA	2.06	2.34	2.06
	TEIXEIRA DUARTE	5.17	4.10	2.45
	Metrostav Inc.	2.40	2.33	2.91
	STRABAG Inc.	2.67	5.17	1.62
	Czech Republic	3.19	2.77	3.10
	Portugal	0.0	0.9	1.0

Source: personally calculated data

To identify more successful company, the data obtained by financial analysis was converted into the rating form with award marks from 1 to 4. The best performance and the worst performance are shown in Tab. 3.

Table 3
Values of obtained average ratios determined for the companies during the study period

	Current Ratio	Quick Ratio	Asset Turnover	Debt Ratio	ROE	ROA	Average ratio
Mota-Engil SGPS SA	3	3	3	4	2	3	3
TEIXEIRA DUARTE	4	4	4	3	1	1	2.83
Metrostav Inc.	1	1	2	1	4	4	2.17
STRABAG Inc.	2	2	1	2	3	2	2

Source: personally calculated data

Selective analysis of financial ratios of firms showed that all selected companies were affected by the financial crisis. Despite the fact that the crisis has had varying degrees of influence depending on the situation in the country, all companies retained their effectiveness on the domestic construction industry market. So in the times of crisis, construction organizations had to stand idling for months which meant that their short-term losses were equal to fixed costs or overhead value. The lack of demand for the products of construction companies limits the scope of their production, generates losses and the amount which would mean bankruptcy for the majority of companies. In addition, special attention should be paid to the ability of the Portuguese companies not only to survive but also to develop in difficult conditions. After all, Portugal is well known to be one of the countries which felt the greatest impact of negative consequences of the crisis.

Financial analysis has revealed that the most successful company has been STRABAG Inc. Portuguese companies have been the most exposed ones to financial risks as a result of the worst economic situation in the country. As a consequence of that, practice of management of the STRABAG Inc. company has been studied by benchmarking method and recommendations for improving the financial situation of other companies have been developed with special attention paid to Mota-Engil.

Firstly it should be noted that all companies could expand business to other countries allowing a stable growth in the medium run at the cost of higher investment. Furthermore, the increase in private investment, often associated with higher margins for example, will allow Mota-Engil Africa to sustain high EBITDA margins for a longer period as well as to reduce substantially requirements.

An effective way of improving solvency as well as both absolute and current liquidity is changes in the structure of assets of the organization. Thus, the increase in solvency is possible to achieve by reducing the value of stocks in the total assets which grew during the analyzed period.

For this is reason it is better to make an inventory of stocks in order to identify the illiquid ones and reduce necessity for these reserves and costs of them.

To carry out activities for improving values by reducing receivables and delaying payment of accounts payable represent a relatively low and negative trend in the development of indicators of solvency.

High receivable levels indicate that the company does not have a well-organized procedure for checking the ability of the customer to pay in advance for the work performed. It is necessary to increase attention of the management paid to the organization of payment and settlement of relations. In addition, it is important to follow the terms of the debt for each debtor separately and take timely actions to recover the debts. It is also necessary to reduce the proportion of accounts receivable in total current assets of the company - it can increase the solvency and ability to pay its obligations to the creditors.

6. Conclusion

Railways, roads, airports and ports deliver economic, social and political benefits to international and regional markets. Adequate transport infrastructure and services are needed to make both international and domestic markets work. When infrastructure is absent or degraded, it no longer fulfils its connective functions and the economy suffers.

Transport infrastructure is expensive. Huge investments required for building highways, railways, airports and ports must be well planned. If regularly maintained, transport infrastructure can have a long life span. But this is not possible without financial health of construction companies and maintenance of their investment attractiveness. Public policy has a significant influence on the activities of enterprises.

First of all it should be noted that according to the analysis of firms, businesses are in different conditions depending on the country in which the companies operate. Currently the conditions of transport infrastructure can generally be rated as highly developed in large parts of Europe. Nevertheless, it must be assumed that the national transport infrastructures in Europe differ substantially. This assumption is primarily due to the fact that national transport policies have developed differently despite the risen influence from Brussels. So, it is important to note that both examined countries have carried out active policy for the development of transport infrastructure by Strategic Plan for Transport and Infrastructure which will have foreseen investments of 2.8 billion Euros in Portugal and 5.6 billion Euros in the Czech Republic in the railway sector up to 2020 (UNECE, 2016).

In order to review these assumptions, it is necessary to make the benchmarking of chosen companies. The following questions need to be answered:

- Who is the best? – Notation of the performance of the transport infrastructure,
- How does the best do it? – Determination of the relevant areas requiring action in terms of transport policy,
- What can we learn from the best practice?

Benchmarking is a tool of strategic management whose objective is to determine the position of the company on the market, while the attention is paid to identifying strengths and weaknesses and improving this position which is compared to competing companies (Holloway, Hinton, Mayle, Francis, 1997).

Despite the above mentioned benefits of benchmarking, also the risks which may occur in stages and steps of benchmarking should be identified. These risks may jeopardize successful use of benchmarking. Most likely problems can arise during planning, data collection, analysis and adaptation. For example during planning, it could be improper setting the course in defining the subject of benchmarking, insufficient or too extensive study in defining depth of benchmarking, unclear purpose and scope of the project or inability to influence the objectives. In data collection, lack of persuasiveness in establishing contacts, inability to obtain certain data, obtaining false information as a result of the inappropriate information source selection, incorrect transfer due to lack of staff qualifications, obtaining unnecessary or vice versa inadequate information because of poor choice of data can occur. Moreover creating a plan couldn't be implemented in adaptation the results of benchmarking if the effect of benchmarking is not fulfilled, due to lack of stakeholder involvement, unwillingness of employees to cooperate because they have not been adequately explained the benefits of the change, due to lack of control over implementation of identified actions and inability to link these plans. For this reason enterprises should prevent these risks. They have to define steps leading to their elimination. The above listed measures eliminate the risks that occur most frequently in the benchmarking process.

Acknowledgements

This paper has been worked out under the project of the specific research at Brno University of Technology no. FAST-S-16-3556 Management of economic processes in the sub-phases of the life cycle of buildings.

References

Babović, J.; Raičević, V.; Carić, M. 2012. Benchmarking as a function of competitiveness and efficiency in business. *Journal of Economics of Agriculture*, (59): 115-127.
Brigham, E. R.; Ehrhardt, M. C. 2011. *Financial Management. Theory and Practice*. 13th edition, South-Western, Nashville, Tennessee, U.S.A.
Calvin, E. 2014. Internal Vs. External Benchmarking Of Insurance Claim Data. Available from internet: <http://insurancethoughtleadership.com/internal-vs-external-benchmarking-of-insurance-claim-data>.
Camp, R. 2006. *Benchmarking: The Search for Industry Best Practices that Lead to Superior Performance*, ASQ Quality Press, Milwaukee, U.S.A.
European Commission 2015. The Commission invests €4.7 billion to improve transport infrastructure in the Czech Republic. Available from internet: <http://ec.europa.eu/regional_policy/en/newsroom/news/2015/05/the-commission-invests-eur4-7-billion-to-improve-transport-infrastructure-in-the-czech-republic>.
Holloway, J.A.; Hinton, C.M.; Mayle, D.T.; Francis, G.A.J. 1997. Why benchmark? Understanding the processes of best practice benchmarking. In *Proceedings of Business, Track, British Academy of Management Conference*, 271-291.
Koráb, V.; Peterka, J.; Režňáková, M. 2008. *Business plan*, Computer Press, Brno, Czech Republic.
Marković, L.; Dutina, V.; Kovačević, M. 2011. Application of benchmarking method in the construction companies, *Journal of Architecture and Civil Engineering*, 9(2): 301-314.
Metrostav. Financial information. Available from internet: <http://www.metrostav.cz>.
MOTAENGIL. Financial information. Available from internet: <www.mota-engil.com>.
Nývltová, R.; Marinič, P. 2010. *Finanční řízení podniku*. 1st ed., Grada Publishing, Praha, Czech Republic.
Philips, B.C.; Kinniry, M.F. 2012. Evaluating global benchmarks. Available from internet: <https://personal.vanguard.com/pdf/icregb.pdf >.
Sheremet, A.; Negashev, E. 2013. *Methods of financial analysis of commercial organizations*. – 2 ed.. and ext. - SIC INFRA-M, Moskow, Russia.
TEIXEIRA DUARTE. Financial information. Available from internet: <http://www.teixeiraduarte.pt>.
UIC eNews, Nr 420. 2014. Portugal: The Strategic Plan for Transport and Infrastructure foresees investments of 2.8 billion euros in the railway sector up to 2020. Available from internet: <http://www.uic.org/com/uic-e-news/420/article/portugal-the-strategic-plan-for?page=thickbox_enews >.
UNECE 2016. Transport Infrastructure Development. Available from internet: <http://www.unece.org/trans/theme_infrastructure.html>.
Wobbe, W. 2000. Benchmarking methods and their application. In Transport benchmarking: methodologies, applications and data needs. In *Proceedings of the Paris conference*, 9-18.

ECONOMIC IMPACTS OF DEVELOPMENT PROJECTS ON TRANSPORT INFRASTRUCTURE IN URBAN AREAS

Daniela Spirkova[1], Marcel Sevela[2], Julius Golej[3], Miroslav Panik[4]
[1,3,4] Institute of Management, Slovak University of Technology in Bratislava, Bratislava, Slovakia
[2] Faculty of Business and Economics Mendel University in Brno, Brno, Czech Republic

Abstract: Investments into construction of development projects evoke considerable demands for further construction of transport infrastructure which development is limited due to the implementation of constraints of the urban environment. Urban space is negatively affected by traffic jams and poor air quality. This means that transport mainly produces emissions that pollute the air, adversely affect the surroundings through increased noise, consumes land and raw materials. The current EU data show that road transport as the largest single type of service is responsible for the largest share of pollution with the production of about 71% of all CO_2 emissions in the transport sector where emissions from passenger cars account for about two thirds. The construction of both new development projects as well as existing buildings is closely related to issue of parking, Which is a long-term problem, both in Slovakia and the Czech Republic. New projects represent an increased demand for parking places and an additional burden for the affected area. Parking costs represent only forced expenditure which investors have to face and often want to save finances upon them. Serious problem of Bratislava and Prague, as the capitals of both countries is precisely the lack of parking places. Parking places are lacking in central areas, but also in housing areas, which is a consequence of sharply increasing number of cars and the lack of conceptual solutions of problems with urban transport. The attempt is to propose solutions based on the concepts implemented in selected foreign examples that use innovative tools and approaches in the field of intelligent transportation. The aim of the paper is a comparative analysis and critical assessment of the current state of static transport in Bratislava and Prague, Which belong to the most densely populated agglomerations in Slovakia and the Czech Republic.

Keywords: development projects, transport infrastructure, urban development, transport economics.

1. Introduction

European cities are important centers of housing, economy, culture and from over 80% of EU GDP. There are more job opportunities than in rural settlements. On the European continent, despite the expected decline in the population, the number of people living in cities by 2050 will increase from 73 to 80%. Urban areas are responsible for a high proportion of total CO_2 emissions from transport, about 23%. Urbanization, greater integration and global cooperation supports economic growth and helps foreign trade, investments and the proliferation of ever-accelerating technological progress. On the other hand, the city is constantly evolving as a result of new development projects, which take over quality agricultural land and increase demands on static traffic.

Most planners and city politicians agree that urban sprawl endangers the sustainability of urban development. There is a clear conflict between the benefits of the few who get better life conditions in the suburbs and the problems of the many whose quality of life is negatively affected by the externalities (environmental consequences of land take and growing traffic) of sprawl. The extremely low price of agricultural land (in most cases good agricultural land) compared to already urbanized land (e.g. brownfield sites) or former industrial sites, is also an important factor underlying urban sprawl. In many development projects, the cost of agricultural land acquisition is relatively low. Thus, it enables greater profits to be made compared to those from already urban land or former industrial waste land, even in cases where no remediation is needed (non-polluted sites) (Oueslati et al, 2015).

An exception are not even the capitals of Slovakia and the Czech Republic, Bratislava and Prague. In connection with spreading of cities and the increasing number of cars, transport problems and problems with parking capacities are growing. The causes are rooted in the past in the context of intensive construction of residential areas from time before 1989, when the vehicle ownership per capita was not as high as it is now and such rapid growth was not foreseen in the future (Fig. 1).

Current problem of transport in these capitals is that they are centre of interest to development companies for the construction of such residential and commercial real estates. Currently (August 2016) in Bratislava are registered 79 new development projects and 115 in Prague, most of them is located near the centers of these capitals. This results in ever increasing number of registered vehicles, and thus the demand for parking spaces.

Private car traffic brings also a range of costs and externalities, such as air quality and noise which both cause reduction of the value of the property in close proximity to busy roads and streets, which also reduces the quality of life for local residents and workers. They can then prefer moving into more remote and less burdened parts of the city. On the other hand, because of inadequate transport infrastructure, they will use primarily vehicular traffic. It is important to realize that transport is not an isolated phenomenon, but an integral expression of land use. Its intensity is also a subject exposed by the structure of the city.

[1] Corresponding author: daniela.spirkova@stuba.sk

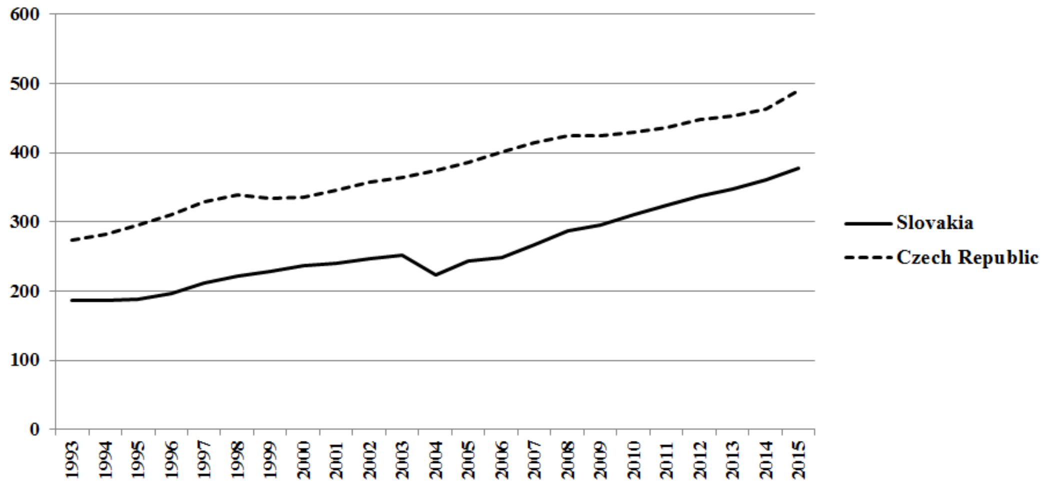


Fig.1.
Motorisation rate (the number of passenger cars per 1 000 inhabitant) 1993 - 2015
Source: Own calculations based on data from the central vehicle register of the Ministry of Interior of the Czech Republic and vehicle registration of the Ministry of Interior of the Slovak Republic

This means that an increasingly large degree of motorization brings in both capitals increasingly greater space requirements. That causes the space became the most valuable object. One of the most serious current problems that closely related to urban space in Bratislava and Prague is the traffic situation, in particular the issue of static traffic. However, space for static traffic cannot be longer solved by organizational measures in communications network and open spaces, as these opportunities are mainly in the city center and already used up. Also current static traffic facilities can not meet the actual needs of the resident population. The problems also becomes with the communications capacities, particularly nodes connecting service and collection roads and approaches to mass storage amenities. Conflicts between vehicular traffic and preferred bicycle and pedestrian movement are also happening more often. Their solution is very difficult, as the overall poor urban concept does not allow to space separation of transport service of automobile transport from walk and bicycle transport even in a recreational location nor in the position of transport service. Last but not least, the static traffic complicates the situation of fire fighters during fire fighting including possible evacuation of people with a high-lift machinery, and most problematic situation is a dense concentration of residential buildings with lack of parking spaces. As an transparent example we can use Petržalka, which is the largest urban area in Bratislava (Spirkova et al., 2014) where the most working population across Bratislava is concentrated.
Car-sharing is an innovative approach to growing traffic problems in major metropolitan areas. Car-sharing is a service that operates on the basis of using a car without owning it, pay insurance and care for its operation and maintenance. For car-sharing could be to some extent considered a renting a company car to its employees. The less often the car is used, the lower the cost of the actual driving (variable costs), while the higher cost of the independent expenses (fixed). The advantages of car sharing are based mainly on financial savings. When driving less than 15 000 km per year, participation in car-sharing is cheaper than owning a car. It is due to elimination of fixed costs - purchase of car, repairs, insurance, accident insurance, car wash and parking fees in the city. User pays only for the time he uses the vehicle. Another positive fact is saving the environment. Although car-sharing user has the same opportunity to use the car as his own, see the real cost per kilometer better and often chooses other ways of transport - go on foot, ride a bicycle or public transport. This limits the unnecessary traffic over short distances. According to a study conducted by the Swiss Office of Energy, it shows that car-sharing users reduce their energy consumption in transport by 50%. Significant benefits of car-sharing can be seen from different views of society and the city:

- Encourages greater use of public transport,
- Increases urban security and reduce traffic jams,
- Improves the availability of the car for everyone, thereby improving the mobility of poorer people,
- Reducing the consumption of fossil fuels,
- It is a tool for more economical utilization of the fleet,
- Supports the local economy,
- Promotes neighborly relations and community,
- Reduces total mileage,
- Reduces emissions and thus saves the environment,
- Replaces old vehicles with new more efficient vehicles,
- Provides a new element of urban mobility.

The sharpest increase in car-sharing users takes place in Europe and the world in the last 10 years. The number of people using car-sharing has increased from less than 20,000 in 1995 to more than 120,000 in 2000. At present, most

systems of this kind are active in Switzerland, Austria and Scandinavia. People can be involved in the system of car-sharing (under different names and in different versions) already in nearly 500 cities in the world. It is also interesting that the addition of urban transport to this system does not require any subsidies from public budgets. All necessary fees will be covered by user (Kutacek, 2003).
One example is the Belgian city of Ghent, where car-sharing is one step for the ambitious urban development strategy called "climate neutral Ghent2050".This strategy is defined by its vision - to be climate-neutral city by 2050 - which focuses on all aspects of the functioning of the city, not only for transport.
As part of that strategy was drawn "plan of solving climate change for the years 2008-2020" (it is an action plan with 105 activities) and "plan to fight air pollution. "It suggests (in addition to car-sharing) a number of specific steps, such as: tools to encourage cycling as an emissions-free transport, 'greener' public transport, low emission zones, traffic management systems and so on. (Bruhova-Foltynova, Jordova, 2012).
Another example is the Spanish city of Donostia-San Sebastián which by promoting sustainable mobility took a number of activities and campaigns, including system car-sharing and car-pooling, etc.

2. Methodology and Materials

In the paper were used the statistical data and analyzes done by Eurostat, the Czech Statistical Office, Statistical Office of the Slovak Republic, Automotive Industry Association and Czech Republic Automotive Industry Association of the Slovak Republic. Based on data from the central vehicle register of the Ministry of Interior of the Czech Republic and vehicle registration of the Ministry of Interior of the Slovak Republic we calculated the motorization rate. This indicator is defined as the number of passenger cars per 1 000 inhabitants. A passenger car is a road motor vehicle, other than a motorcycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver); the term "passenger car" therefore covers micro-cars (need no permit to be driven), taxis and hired passenger cars, provided that they have fewer than 10 seats; this category may also include pick-ups. Further were analyzed the selected documents and regulations of capitals of the Slovak Republic (General regional transport plan of capital Bratislava and Methodology of traffic capacitive impact assessment of investment projects) and the Czech Republic (Prague construction regulations and Vision for mobility and public space - Prague 2025), which are the starting points for tackling the problems of the static traffic. Prague construction regulations regulate the system for calculating the capacity of parking for new construction. The document "Vision for Mobility and Public Space - Prague 2025" includes solutions of reduction of the demand for automobile transport in the wider center. This is a promotion and implementation of alternative transport such as car-sharing, carpooling, and so on.

3. Results and Discussion

The problem in a comprehensive transport solutions in Bratislava is the lack of sufficient database of traffic data and the city/0} does not have detailed current conditions of its urban road network. City of Bratislava lacks regular traffic surveys and the results which would show the disproportions for current situation and predict its evolution (Methodology of capacitive traffic impact assessment of investment projects, 2014). In accordance with the approved Methodology of traffic capacitive impact assessment of investment projects in 2014, it is important that any investment project (or group) in defined range should be subjected with traffic engineering analysis to preparatory documentation in space and time in order to benefit and demonstrate the carrying capacity of the territory of the new road infrastructure. One of the starting points of this methodology with regard to development activities Bratislava was the definition of an investment project - "building investments whose primary requirements for static traffic excess 300 new parking places." The results obtained using the above methodology should enable the developer to obtain information primarily on the extent and quality of the increased load of dynamic and static traffic in the area of interest in terms of their upcoming projects and propose solutions and measures which will eliminate negative impacts on the territory.
The general regional transport plan of capital Bratislava shows (December 2015) that the City of Bratislava is a city with monocentric structure and highly concentrated built-up area of 8 clearly identifiable urban units, which are located in 4 urbanization axis. Acording to Bertaud (2009) “The Classical Monocentric model: strong high density center with high concentration of jobs and armentities, radial movements of people from periphery toward center”.
Capacity for parking in Prague for new construction determine Prague building regulations (PBR), which reflect the new paradigm of so-called compact city, which opposes the principles of the Athens Charter. Prague has in comparison with the Czech Republic its own specific building legislation. The fact that the City of Prague can adjust the requirements for land use and construction by itself from the rest of the Czech Republic, with the importance and specific nature of the construction in the city. The current version of the (PBR) enters into force on August 1st 2016. It establishes minimum, but also the maximum number of parking places and addresses storing bicycles. PBR ideologically reflect new urban trends (Wien, Zurych, Berlin, Copenhagen) and revive traditional planning tools emphasizing block development, town-creating elements, the quality of public spaces, and economically sustainable living and ground green parter. Their implementation has been the subject of professional and institutional disputes. Generally, the PBR is considered as more liberal. PBR provides solutions for a system of calculation parking capacity. Conversion works by determining the percentage of the basic number of parking spaces for each zone in the area by land plan in the Annex of given regulation. The aim is to make the illegal parking worthless. Even so, some opinions consider the requirements for parking as excessive and forcing builders to construct unnecessary parking with negative

impact on the price of the apartments. In Vienna, a city typologically similar to Prague, was created the project of house (Bike-City), which is adapted to the purpose of its inhabitants who prefer bicycle transport (the housing project "Bike-City“ focuses on the needs of bicyclists, but the true innovation came about by convincing the Vienna government to exempt the development from obligatory parking lot legislation. Accordingly, money that would have been put into constructing parking space has been invested in facilities that directly improve the resident's standard of living. The project has received a lot of attention and has already resulted in plans for another bike-city project in Vienna).
For individual purposes of use is in the appendix 2 of (PBR) established indicator of the basic number of parking spaces, which is defined by gross floor area of the purpose of use of 1 m^2 per parking space. For the family house (the use for housing) is necessary to establish one parking space per 85 m^2 of gross floor area (GFA) for purpose of living. It is up to the gross floor area (see § 2 letter g + comment on p. 48 of publication) of a family house, to GFA for the purposes of calculating of the necessary parking spaces are not included areas of garages, basements, technical and auxiliary premises and technical infrastructure facilities. At the same time it introduces a correction of max. 2 spaces per apartment. So if the calculation result in more parking spaces than 2 spaces per apartment, for a base number of parking space is used the number of housing units x 2 parking spaces.
In the centre of Prague already are thousands of parking spaces which nobody uses. If the construction regulations for the central part of the city do not have set a limit for the number of parking spaces, then it should be an upper limit, not lower.
Parking places are distinguished as binding (for the users of buildings) and visitor parking. The resulting number of places is limited on both sides (minimum and maximum) and is calculated separately for housing and other purposes of use of buildings. Besides the capacity requirements, determined are also requirements as the form and character of (method of location) parking lots, their landscaping, etc. Paradoxically, now more parking problems show Prague postwar neighborhoods than the inner city. Limiting the number of parking spaces is fairly effective regulator - generally traffic is efficiently regulated by the capacity limits on the principle of traffic induction and reduction that are valid also for transport at quiet period of day. Lack of parking is a mental barrier for the decision to go by car. Copenhagen for 30 years reduces in the city center every year 2% of parking places in the streets. Zurych and Bern set a ceiling for parking capacity in the city center according to limit from 1993 and approval of the construction of additional parking places in conditioned by cancellation of a parking space on the street.
Quite surprisingly public in Prague absorb new paradigm of public space and parking itself ceases to be seen as a key aspect of quality of life.
The key problem of Prague transport is transport that is consequence of chaotic suburbanization of the Nineties. From the so-called satellites arrive to the city center thousands of cars that have no place to park, where construction of Park & Ride parking spaces is limited by the lack of suitable land on the outskirts. Generally, new urban trends (e.g. Danish architect Jan Gehl) emphasize more human scale and quality of public areas and divert it from adapting town planning transport infrastructure. It can be assumed that some of the new technological and socio-economic trends (autonomous transport, car-sharing), help to implement this approach faster. A key condition of such an approach is sufficient quality of public transport, public spaces as well as a shift in the value scales of municipal representation and residents.
Paid parking zones are distinguished by colored stripe on the table under additional traffic signs indicating parking (see Fig. 2):

- **Blue Zone**: parking allowed to residents and subscribers - citizens and entrepreneurs residing in the district, based on the purchased parking card (parking card do not guarantee a free parking place to its holder); In legal terms, the blue parking zones are reserved parking places which means that towing illegally parked vehicle is possible even when it is not causing an traffic obstruction,
- **Orange zone**: short-term parking (up to 2 hours) - with payment using parking meter;,
- **Green Zone**: mid-term parking (up to 6 hours) with payment using parking meter,
- **Reserved parking**: For disabled people is parking characterized by lawful claim; for other subjects usually by special permit of road use; with commercial entities with significant charge.

The system is functional since autumn 2014 with four types of zones. Existing **green areas** for mid-term parking **are replaced with mixed purple zones**, **newly to be introduced green zones for selected types of vehicles.**
Mixed zone (purple) during the day (tentatively set for a period from 8 a.m. until 8 p.m.). There can park in addition to residents also other drivers, parking is paid.
Visitor Zone (orange): paid parking with limited time up to two hours, designed for medical centers and offices.
Residential zone (blue).
Ecological zone (green) for ecological cars and trucks in the system of car-sharing.

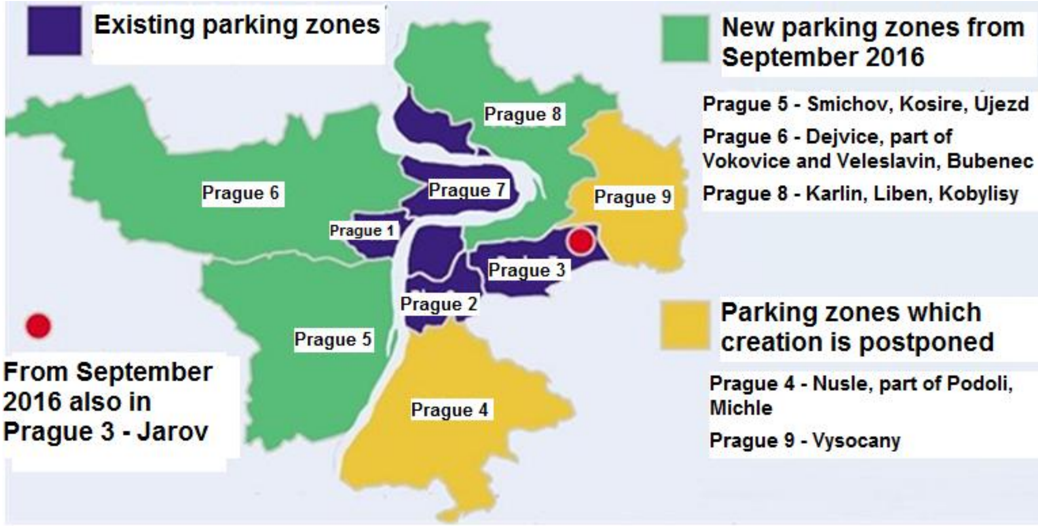


Fig. 2.
New parking zones in Prague
Source: www.praha.cz

4. Conclusion

The fact is that both cities are centers of interest to development companies for the construction of such residential and commercial real estates which results in increasing rate of motorization. Furthermore, it is non-existent support system of public transport, demand, lack of parking places and pressure from developers. Each function generates a certain number of parking places.
The problem of parking in Prague is generally not related with some kind of planar lack of parking spaces. In Prague's neighborhoods (relatively autonomous neighborhoods) is realized since 2007 (in the narrow historic center since 1996) the introduction of so-called blue zones, which in fact allows parking only for residents. The pricing policy of parking permits in each district differ fundamentally, however, it depends on the rule that for residents (household), the price for parking one car is negligible, but for parking the next second, third car is very expensive. The number of districts, which regulate parking, gradually increases from the center to the periphery of the city, because of the introduction of the regulation, part of drivers move to cross-border city district.
Basic problems with parking in Bratislava can be summarized into four areas:

1. Illegal but also legal, but standing with adverse impact on traffic safety, throughput of local communications for emergency vehicles as well as pedestrians and cyclists. Vehicles parked on the sidewalk, on the grass, at the crossroads, on bike paths, squares and pedestrian zones. Public space then looks like the car park where pedestrians "intertwine" between cars,
2. Paying recklessness exceeds 50%. This significantly influences the transport behavior of residents and visitors - car becomes quick and cheap way transport when traveling to Bratislava,
3. Resident parking does not have a common form and the rules in the city. Ownership of more than one vehicle is not specially charged and vehicles are parked on a public space. Lack of regulation that blocks the efficient introduction of the concept of sharing (car sharing, car pooling), greater modal split in favor of public transport and encouraging cycling.,
4. Missing comparison between the offers of transport methods, i.e. navigation / mobile application / website informing the public about travel alternatives (implemented in established and immutable routes and methods of transport), for example navigation for cyclists (map of safe cycle tracks with speed information) and the necessary infrastructure (e.g. a secure storage for bicycles).

Due to request of Old Town (central and historical part of the Bratislava) were commissioned a static transport analysis and paid parking project in the area of this city district. The expected solution is to create a simple and transparent system, where nobody will have the right to reserved parking, all parking spaces will be available to all drivers. Regulatory tool of static traffic in the Old Town should be the price of parking, and residents just like everywhere in the world will have an advantage over visitors and the introduction of short-term parking - limited up to two hours. City of Prague was used as an example for the drafting of solutions to the problems of static traffic due to many years of successful experience in this field.

References

Bertaud, A. 2009. *Urban Spatial Structures, Mobility and The Environment*, World Bank, Washington D.C, U.S.A.

Bruhova-Foltynova, H.; Jordova, R. 2012. Innovative tools of sustainable mobility in the European urban regions: Experience with the assessment and the role of political barriers (Inovativní nástroje udržitelné mobility v evropských městských oblastech: zkušenosti s evaluací a role politických bariér). In *Proceedings of the 5th Czecho-Slovak conference „Transport, Health and Environment"*.

Kutacek, S. 2003. *Possibilities of Alternatives for Individual Automobile transport (Možnosti alternativ k individuální automobilové dopravě),* Masaryk University, Brno, Czech Republic.

Oueslati, W.; Alvanides, S.; Garrod, G. 2015. Determinants of urban sprawl in European cities. *Urban Studies*, 52(9): 1594-1614.

Schlosser, T. 2014. Proposal for an amendment of the Methodology of traffic capacitive impact assessment of investment projects. 11 p.

Spirkova, D.; Golej, J.; Panik, M. 2014. The issue of urban static traffic on selected examples in Bratislava in the context of economic sustainability. conference. In *Proceedings of the 2nd International Conference on Traffic and Transport Engineering (ICTTE),* 629-635.

Statistial Office of the Slovak Republic. 2013. Available from Internet <http://portal.statistics.sk/>.

Methodology of traffic capacitive impact assessment of investment projects. 2014. The Annex to Decision of the Mayor of the capital city of the Slovak Republic, Bratislava, Slovakia.

The generel regional transport plan of capital Bratislava 2015 (Územný generel dopravy hlavného mesta SR Bratislava). Available from Internet: <*http://www.bratislava.sk/*>.

Composition of the Vehicle Fleet in the Czech Republic (Složení vozového parku v ČR). Available from Internet: <http://www.autosap.cz/zakladni-prehledy-a-udaje/slozeni-vozoveho-parku-v-cr/>.

Vision for mobility and public space in Prague 2025 (Vize pro mobilitu a veřejný prostor Praha 2025). Available from Internet: <http://www.gjf.cz/publikace/vize-pro-mobilitu-a-verejny-prostor-praha-2025/>.

PROVABLE LOSS IN PUBLIC LINE TRANSPORT AND TRACK-BASED PASSENGER TRANSPORT

Jiří Čejka[1], Martin Telecký[2]
[1] *Institute of Technology and Business in České Budějovice, Department of Informatics and Natural Sciences, Czech Republic*
[2] *University of South Bohemia in České Budějovice, Faculty of Economics, Department of Accounting and Finance, Czech Republic*

Abstract: The transport policy of the government in ensuring the transportation performs a critical function, be it the public line transport or the track-based passenger transport. The government here stipulates the basic international legislation and agreements. The transport companies must agree the terms and conditions which are included in the public service contract with the specific client (municipality, region, state). The terms and conditions are related to the determination of the amount of a provable loss, adequate profit and consequent paying to the relevant transport companies from the public budgets of the different tiers of government. The calculation of a provable loss and other indicators is regulated, as to its development, by Regulation No. 241/2005 Sb. and Regulation No. 493/2004 Sb. What is more, it does not have to always meet the requirement of capturing the objective reality.

Keywords: public line transport, public track-based passenger transport, public urban transport, provable loss, adequate profit, economically substantiated costs.

1. Introduction

Ensuring of the traffic services is included in the primary services that the inhabitants and tourists are provided with by the state, regions and private carriers for a certain price. Besides the public line transport, also the public track-based passenger transport must be financed from the public budgets in individual regions of the Czech Republic. An important indicator for the potential cash injection for the transport companies in the public line transport or the public track-based passenger transport is a provable loss. The attention paid to this indicator may be, hence, deemed necessary. This paper is aimed to analyse Regulation No. 241/2005 Sb. on the provable loss in the public track-based passenger transport and on the definition of the parallel public passenger transport, Regulation No. 493/2004 Sb., regulating the provable loss in the public line transport and specifying the method of the exercise of the professional government supervision in the road transport over funding the traffic services, and Regulation No. 296/2010 Sb. on the procedures for establishing the financial model and setting the maximum amount of the compensation. Based on the analysis of the above regulations, it is necessary to draw up the information on the adequate profit and the classification of the substantiated costs and sales. These regulations will be compared and their differences and deficiencies will be pointed out.

2. Financing of public passenger transport

2.1. Provable loss in the public line transport

In case of the public line transport, the "provable loss" term is defined (pursuant to Regulation No. 493/2004 Sb.) as the difference between the sum of the economically substantiated costs and the modified adequate profit and the earned receipts and revenue.

2.2. Provable loss in the public track-based passenger transport

In case of the public track-based passenger transport, the provable loss is stipulated as the "*difference between the amount of economically substantiated costs increased by the adequate profit and the total revenue from the operation of the public track-based passenger transport using the regional and nationwide transport trains".*
To calculate the provable loss, the carrier has to allocate the economically substantiated costs to the stretches of tracks separately for the trains serving the regional transport and the nationwide transport and to divide them into the territorial districts.
Based on the basic report of the costs and revenues from the transport activity in the public track-based passenger transport, the following is included in the revenues:

- Receipts from the fare,
- Receipts from the luggage transportation,
- Receipts from the surcharges and fines for failure to meet the transportation code,
- Receipts from other services related to the passenger transport,
- Loss paid from the pupils´ fare.

[1] Corresponding author: cejka.jirka@volny.cz

In the public track-based passenger transport, the total revenues will be ascertained upon all types of the income transport documents maintained in the carrier´s accounting system. The receipts from the fare will be divided for the regional transport trains and the nationwide transport trains and then according to individual territorial districts of the region. The loss paid from the pupils´ fare will be calculated as the difference of the fare without the discount for the pupils´ fare and the fare with the discount for the pupils´ fare. The loss paid from the pupils´ fare (prices excl. VAT) is calculated and submitted to the Ministry of Transportation by the carrier himself to be paid the provable loss. The more exact terms and conditions are set forth in the public service contract.
The provable loss is covered from public budgets (of municipalities and regions); more exact terms and conditions for payment of the loss are provided in the public service contract concluded between the client and the carrier. Under this contract, the provable loss may be paid out as advance payments for every quarter provided that the preliminary report of costs and receipts from the transportation activity in the public line transport and the track-based passenger transport is made. These financial means designed to cover the provable loss cannot be used for any other business purposes.

2.3. Adequate profit in public line transport

Another important indicator is the adequate profit in the public line transport and the track-based passenger transport.
Regulation No. 493/2004 Sb. defines the "adequate profit" term. *"The amount calculated as the sum of the amount which after taxation and a minimum allocation to the mandatory funds does not exceed 1/8 of the price of buses used, as a rule, for the public line transport by meeting the public service obligation, and the amount which does not exceed the share of the price of investment related to the operation of the public line transportation corresponding to the service life as per the special law provided that the transportation authority (client) has given consent to inclusion of these investments into the calculation of the provable loss."*
$[(\frac{number\ of\ buses\ x\ price\ of\ a\ bus}{8} - depreciation\ of\ buses)/coefficient]$ – earmarked subsidy from the state budget and the client´s budget for the purchase of buses,
where:
The coefficient is calculated as follows: $\frac{100-\%\ income\ tax}{100}$. The coefficient is used for the needs of including the corporate income tax.
Under the contract, the carriers are allowed to pay out the adequate profit, which is designed for the renewal of vehicles in the public line transport and the urban public transport (buses) only. As well as the provable loss, the adequate profit cannot be spent on any other business purposes. It is understood as an option of obtaining the financial means (resources) for the rolling stock renewal.

2.4. Adequate profit in public track-based passenger transport

Pursuant to Regulation No. 241/2005 Sb. the adequate profit in the public track-based passenger transport must not exceed 5 % of the economically substantiated costs.

3. Classification of economically substantiated costs

For calculating the provable loss and the adequate profit, it is necessary to classify the economically substantiated costs. The economically substantiated costs pursuant to Regulation No. 493/2004 Sb. on the provable loss and Regulation No. 241/2005 Sb. are classified as follows:

- **Fuel** – consumption of fuel, consumption of diesel, oil, gasoline, lubricants for the mileage in the bus line transport for the whole accounting entity
- **Traction energy, traction diesel on the rolling stock, traction energy on trolleybuses**
- **Rubber rims** – new tyres, inner tubes, valves, etc.
- **Other direct material** – spare parts, electric parts, cleaning and washing detergents, anti-freezing mixtures, uniforms, protective aids, common repairs (it is a direct material directly consumed for the buses, rolling stock)
- **Direct wages** – wages of drivers, inspectors, guards/conductors, cleaning staff, cash desk personnel, technical and economic staff, etc.
- **Depreciation of buses** – depreciation of the buses, tangible fixed assets which are directly associated with the bus line transport, depreciation of the capital goods related to the information system of the pre-sale of tickets; the accounting entity will determine the procedures for the fixed assets depreciation and will set the depreciation rates by itself (as per the performance, in terms of time, etc.).
- **Depreciation of the rolling stock –** only the accounting depreciation, see the Depreciation of buses.
- **Means of transport leasing** – lease instalments for the means of transport, equipment related to the operation of the public line transportation, cost of down payment
- **Repairs and maintenance of buses** – external repairs quantified upon individual invoices, their own repairs
- **Road tax** – buses providing the internal national transport are exempt from the road tax

- **Third party liability insurance** – it is the statutory insurance and the collision insurance related to the bus line transport and the public track-based passenger transport
- **Fare** – travel costs pursuant to the Transport Compensations Act
- **Payments to the funds** – social security insurance, contribution to the State employment policy and the premium paid for the general health insurance
- **Overhead costs** – costs directly related to the bus transport operation and the regular line transport operation; the accounting entity must determine the method of the overhead cost dissolution in the contract (as per the mileage, number of drivers and vehicles, or based on the operating costs); the method of the overhead cost dissolution is established upon the travelled train-kilometers in the public track-based passenger transport
- **Charges for the use of the rails, if the carrier is not an owner of such rails. In this case, the carrier will make an agreement with the Railway Infrastructure Administration (RIA, the Czech abbreviation: SZDC)**

Prior to making the contract, all cost items directly related to providing traffic services must be discussed.

4. Regulation No. 296/2010 Sb. on the procedures for establishing the financial model and determining the maximum amount of compensation

The Regulation No. 296/2010 on the procedures for establishing the financial model and determining the maximum amount of compensation supersedes the term "provable loss and the adequate profit" by the term "amount of compensation."

Under the new regulation, the carrier is required to submit to the client all information on the situation of its assets related to providing the traffic services, the performance and all activities. The carrier is thus more intensively controlled and the more demanding requirements are applied than in case of the previous regulations.

The maximum amount of compensation will be calculated in the same way as the adequate profit, however, the requirement of the maximum permissible rate of return per the capital must be met.

Pursuant to Regulation No. 296/2010 Sb., each carrier is required to report all of its operating assets before making the contract. This necessity was not directly required in Regulation No. 493/2004 Sb. The reason for reporting operating assets is a new requirement for not exceeding the maximum permissible rate of return per the capital, being 7.5 % annually from the operating assets. The maximum permissible rate of return per the capital is calculated as a share of net income and the value of operating assets under the public service contract. Only the value of operating assets in the amortised cost at the end of the immediately preceding accounting period will be included in the operating assets.

The transportation companies must use the assets which are always procured and recorded as their property. To calculate the adequate profit, it is necessary to determine the exact amount of depreciation and the average prices of buses providing the traffic services. In case of the public track-based passenger transport, it must not exceed 5 % of the economically substantiated costs.

If the assets are leased, the carrier may include only the first extraordinary instalment to the leasing company in the operating assets and reduce its value evenly throughout the leasing period. In case of the leaseback, the assets must not be included in the operating assets. The accounting entity will post the leaseback in the Other revenue item. The leasing company then becomes the owner of a vehicle. The carrier will then only pay the rent to the company. The rent may show only indirectly in the costs per the output unit (km).

Pursuant to Regulation No. 296/2010 Sb. on the procedures for establishing the financial model and determining the maximum amount of compensation, the sales in the public line transport and the track-based passenger transport are divided as follows:

- Sales from the fare (sales obtained from passengers – fare)
- Other sales from transportation (sales from the luggage transportation, other surcharges for failure to meet the transportation code)
- Other revenue (revenue from the sale of the fixed assets is not included; pursuant to the agreement in the "contract", we can include the revenue from the sale of assets in case of the leaseback transaction which can accrue throughout the leasing period).

Regulation No. 296/2010 Sb. divides the revenues (sales) into three groups. The reason is better explanatory power and correct posting of some sales or revenues in the required group of revenues (sales).

Pursuant to Regulation No. 296/2010 Sb. the initial financial model must be established prior to making the contract and all prerequisites and the expected development must be known so that the net income is not a negative value.

If the costs in the report on the actual costs and revenue in the public line transport and the public track-based passenger transport are lower than in the initial financial model or if the revenue is higher, the accounting entity will return the different amount of compensation to the client or will transfer the difference into the next period as agreed in the contract. If the actual costs are, on the other hand, higher than in the initial financial model, only a half of the value from the different deviation will be paid. With respect to financing of the traffic services, it is not the incentive behavior. The carrier is bound by the contract where these facts are usually addressed. A specific addendum to the contract is, moreover, concluded to unambiguously specify the financial amount to be paid to the carrier by the client.

The contract may require the payment of the full amount compensation.

5. Conclusion

Many carriers who have made the public service contracts follow the still valid Regulation No. 493/2004 Sb. and Regulation No. 241/2005 Sb. After the contract terminates, however, a new contract will have to be made. This contract will already contain the new rules and conditions of payment of a maximum amount of compensation pursuant to Regulation 296/2010 Sb. The principle of paying the maximum amount of compensation is similar to that of the provable loss and the adequate profit, however, the older terms were replaced with the new ones, and the new rules and the new reports with newly divided costs and sales were created to determine the maximum amount of compensation. The Regulation No. 296/2010 Sb. requires more detail information on the carrier providing the traffic services to avoid unnecessary overestimating of the amount of compensation. Regulation No. 493/2004 Sb. and Regulation No. 241/2005 Sb. do not require these detail requirements; they, however, must be determined in the contract between the carrier and the client. Originally, the requirements were negotiated between the carrier and the relevant transport authority. The payment of the provable loss and the adequate profit (maximum amount of compensation) is mostly negotiated in the contracts and may deviate from the relevant regulation. The conditions and the method of determining the adequate profit are individually set forth in every region in the public service contract. If 5 % of the adequate profit is taken into account in the public track-based passenger transport, it is, basically, a very reasonable percentage of the economically substantiated costs. In many contracts made with the carriers, approximately 2 % of the economically substantiated costs are reckoned with.

Regulation No. 296/2010 Sb. requires that every carrier submits to the client the situation of its assets, without the operating assets, which the carrier directly uses to ensure the traffic services. In my opinion, this condition is satisfactory as the maximum amount of compensation is established in this way. Upon the amortised cost the client receives the information on the age of the rolling stock and, finally, provides higher compensation for the renewal of the older rolling stock with partially new vehicles.

For the purposes of the cost breakdown in the track-based transport, the procedure for determining the amount of the provable loss is insufficient. The reason is especially the use of the heterogeneous group of the powered and non-powered vehicles on the same lines, the different capacity of trains and other factors. These facts have a significant influence on the operating costs of individual lines.

The task was to compare two basic regulations in the public transport which determine the amount of the provable loss and the adequate profit. Regulation No. 493/2004 Sb. and Regulation No. 241/2005 Sb. were superseded with Regulation No. 296/2010 Sb., which already meets the European standards and requires more detail information on the accounting entity providing the traffic services. The advantage of Regulation No. 493/2004 Sb. is not the requirement for not exceeding the maximum permissible rate of return per the capital, but the carrier obtains just a part of compensation under the terms and conditions of the contract. The accounting entity must present to the client the initial financial models including the initial costs and sales (revenue) and the report of operating assets and prepare the reports of actual costs and sales (revenue) at the end of the accounting period and resolve the deviations, if any. This will remove the risk of overestimating the cost items and increasing the net profit which is closely related to the amount of compensation. Most transport companies still have the valid public service contract pursuant to Regulation No. 493/2004 Sb. and Regulation No. 241/2005 Sb. For the external users it would be good to specify in more detail some cost and revenue items in order to make the explanatory power of the reports more efficient. The Regulation No. 296/2010 Sb. lays down the basic requirements upon which the maximum amount of compensation is calculated by means of establishing the initial and actual financial models. For calculating the net profit, it is necessary to know the amount of operating assets included in the report of operating assets. The Regulation should, however, justify in more detail why some items are not included in the total value of operating assets.

References

Červenka, M. Trend reversal in financing the public transport. Available from Internet: <http://kvf.vse.cz/storage/1180450696_sb_cervenka.pdf>.

Rails Act No. 266/1994 Sb., as amended. Available from Internet: <www.mikrat.cz/files/ZKN_266-1994.pdf >.

Regulation of the Ministry of Transport No. 241/2005 Sb. on the provable loss in the public track-based passenger transport and the definition of the parallel public passenger transport (in relation to the contracts concluded with the carriers). Available from Internet: <www.mdcr.cz/NR/rdonlyres/DB610103-96CC-49E8.../0/V2412005prokztrata.rtf>.

Decree of the Czech Republic Government No. 493/2004 Sb. regulating the provable loss in the public line transport and establishing the method of exercise of the professional government supervision in the road transport over funding of the traffic services. Available from Internet: <www.sagit.cz/info/sb-anotace-sb04493a>.

No. 296/2010 Sb. on the procedures for establishing the financial model and determining the maximum amount of compensation. Available from Internet: <www.zakonypreludi.sk/zz/2010-296>.

Telecký, M. 2015. *Financial and Accounting Issue in the Selected Area of Public Transport*. In INPROFORUM 2015. University of South Bohemia in Ceske Budejovice. Faculty of Economics. Department of Accounting and Finance, 237-244.

Telecký, M.; Kouřilová, J. 2015. The economic impacts of legislative changes in the areas of finance, accounting and taxes (part 2), *Indicator of the provable loss in public line transport and public track-based passenger transport*, 98-104.

THE COMPARISON OF PUBLIC ROAD AND RAILWAY TRANSPORT COSTS

Václav Cempírek[1], Petr Nachtigall[2], Petr Novák[3], Matěj Pluhař[4]
[1,2,3,4] The University of Pardubice, Jan Perner Transport Faculty, Pardubice, Czech Republic

Abstract: This article compares the costs of public road and railway regional passenger transport in the district of Pardubice. The article focuses on the differences in unit costs between two means of transport, the objective point of view of the road and railway transport costs in the Pardubice region. The topic of the solution is the classification of the differences in costs for road and railway passenger transport because road transport does not include costs for road infrastructure.

Keywords: costs, railway transport, road transport, fees.

1. Introduction

In terms of costs, we can observe significant financial differences and completely unlike approach to cost issues between road and railway transport. In railway transport, we have to distinguish whether the commissioner acts in the interest of the state transport services (i.e. the state through the Ministry of Transport of the Czech Republic) or to secure regional transport service.

Road bus transport in the Czech Republic is commissioned solely for the needs of regional transport services; so-called long distance (or other) lines operate accepting the business risks and their costs are hence covered by the transport carrier. In terms of actual costs processing, we have to differentiate several calculations, which are described later in the article. In another part we investigate and calculate actual costs for a chosen example, especially with respect to fees paid for use of railway infrastructure; the calculation, procedure, and fees are more or less different in every European country.

2. Defining the costs of the Pardubice Region

Defining the costs of the Pardubice Region (PR) is based on the fact, that PR grants subsidies from the Regional Office´s budget for both bus and railway public regional transport. This cost defining is based on actual costs paid by PR to individual transport companies under contracts concluded according to the Act No. 194/2010 Coll., On Public Services in Passenger Transport and amending other acts; between PR and individual transport carriers.

It must be pointed out that these actual costs are not those that are borne by the transport company itself, but those borne by the Pardubice Region. This study investigates these costs of the transport company because the amount of compensation and hence costs of PR depends on these costs as a part of income, revenues and subsidies determined on the basis of transport carrier´s "financial model".

The range of planned services in road transport was set as high as 16,110,377 bus-km for the year 2015 with overall compensation for all transport companies at CZK 299,542,449 and an average subsidy of CZK 18.60 per bus-km.

On the other hand, the range of planned serviced in regional rail transport was set to 4,776,692 train-km for the same year with overall subsidy valuing CZK 478,264,460 and hence an average compensation of CZK 100,12 per train-km.

The subsidy is paid from the PR's budget in costs of transport services. On the basis of the Czech Government Resolution No. 1132 of August 31, 2009, and the Czech Government Resolution No. 1350 dated October 28, 2009, the State participation in funding railway transport for long-distance transport was approved by a concluded Memorandum about the commitment by the State to finance regional rail transport.

Five variants were selected for the processing procedure and as well as the basis for alternative calculations and comparison of the cost of a public road and railway regional transport.

The actual processing of costs of securing the transport services was carried out in four variants and its results are shown in a table following the description.

- **Variant No. 0** (Current state) is a current state variant that is used to determine the cost of both types of public regional transport. This alternative does not represent the result to this study but it is shown for the complexity of the solution,
- **Variant No. 1** (Direct costs calculation) is based on actual cost of the transport carrier (total financial cost) processed on every route (on every line) and therefore also on collated data from individual routes or lines for the full range of provided transport services in train- and bus-km. On the basis of thus identified transport company cost it is possible to compare the cost of public road and railway transport by cleansing the cost of railway carrier (variant No. 2) or by increasing the cost of road carrier (variant No. 3) and by this to achieve comparable base for both public transport types,
- **Variant No. 2** (Comparable cost – railway transport adjusted) is based on cleansing the costs of both transport modules so that are comparable. The costs are stated in three categories: comparable, incomparable and

[4] Corresponding author: matej.pluhar@student.upce.cz

adjusted. For the purposes of cost comparison, the adjusted costs of the railway carrier are used (without infrastructure cost, without the cost of levy for renewable electricity sources and the costs of building fund).

- **Variant No. 3** (Comparable cost – road transport increased) focuses on problem of different range of costs by increasing the cost of the road carrier by infrastructure cost and cost of other services that need to be covered by railway carrier on its own account but not by the road carrier (such as maintenance, repair and investments into the road system, IRS, the Regional Office staff, etc.),
- **Variant No. 4** – this alternative, according to the methodology set up by Transport Bulletin 11/2013, issued by the Ministry of Transport of the Czech Republic quantifies **external costs.** (The ministry od Transport, 2016).

Table 1
Comparison of variants

Variant	Transport type	Per 1 km	Per 1 seat-km	Per 1 customer	Per 1 passenger-km
		[CZK]	[CZK]	[CZK]	[CZK]
0	Train	100,12	0,67	44,49	2,80
	Bus	18,60	0,41	26,16	2,63
1	Train	111,68	15,52	x	x
	Bus	120,84	31,33	x	x
2	Train	88,26	0,59	39,22	2,47
	Bus	18,60	0,41	26,16	2,63
3	Train	100,12	0,67	44,49	2,80
	Bus	25,14	0,56	35,28	3,54
4	Train	125,42	0,84	55,73	3,51
	Bus	36,12	0,80	50,73	5,09

However, the **other European countries** should be also checked, how they process their transport costs. The calculation of fees for use of railway infrastructure, when compared to other countries, takes into the account similar conditions of railway categories in Pardubice Region, which are set up as following:

- **category of nationwide** (corridor) electrified lines, for example, Česká Třebová – Pardubice,
- **category of regional lines**, for example, Pardubice – Hradec Králové or Pardubice – Havlíčkův Brod,
- **category of secondary lines**, such as f. e. Choceň – Litomyšl or Přelouč – Prachovice.

Fees for use of railway infrastructure in some EU countries
It was decided for a model calculation because the actual comparable data from individual countries cannot be obtained due to their confidentiality.
For a **model calculation of fee for use of railway infrastructure, a trainset** consisting of a motor unit of 844 series (RegioShark) was chosen, which also consists of two connected carriages with the capacity of 120 seats and weights 84.4 tons (and has 6 axles). The train journey is 50 km in one direction. The prices do not include any other costs like depreciation, wages, energy, etc., are in CZK without VAT and are displayed in Table 2 below.

Table 2
Comparison of individual countries

Country / Line category:	Czech Republic	Slovakia	Poland	Austria	Germany
European line (corridor), electrified:	579.00	1 669.00	2 479.00	2 879.00	6 141.00
Nationwide line, electrified:	475.00	1 557.00	1 813.00	2 139.00	4 358.00
Regional line (secondary), non-electrified:	357.00	1 543.00	1 252.00	1 609.00	4 000.00

Fees for use of railway infrastructure (economic cost item) in the case of public transport in the Czech Republic are **still at some 25 - 35 % in comparison with Slovakia and remain the lowest in whole Europe**.
Such fee settings **may be associated with subsidizing these costs on railway infrastructure from the state budget**. It may be inferred that more funds the governments in other countries save on using the railway infrastructure, the more

they must provide from the state budget for subsidized fares (as reimbursement to counties) in public transport directly to particular carriers.
As an example of another model of charges for using transport infrastructure, **let us take Austria**, where, for the purpose of determining the amount of fees for use of railway infrastructure, the lines are divided into five categories:

- Mountain line through the Brenner Pass (most expensive) = 3.6514 EUR / km,
- Additional rail network (terminating branch lines) = 1.0856 EUR / km[2*],
- Other international lines = 2.0248 EUR / km[3*],
- Other mainline railway network = 1.4778 EUR / km[4*],
- Western main haul (second most expensive) = 2.9923 EUR / km ,

The highest fees for use of railway infrastructure can be, as expected, found in Germany. There, it is considered to be a model of a hidden railway infrastructure financing by the state. Regarding the high public transport fares, those are paid by individual federal states and the government hence receives some funds from the federal states back. Due to the fact that fees for use of railway infrastructure do not distinguish the train´s weight (it is paid per so-called route-km), this is used to secretly finance the freight transport as well. The surcharge for freight trains is calculated for trains with a total weight of more than 3,000 tons in total of 0.96 EUR / CZK 26.50 per kilometer. The only difference is then a surcharge of 2% to the overall price in case the freight train does not consist of 90% of railcars equipped with noiseless ("silent") brakes. (Zajíček, 2010), (Soušek, Říha, 2014).

3. Theoretical approach for setting the comparability of costs in individual transport modes:

Now let´s compare bus and rail transport. To be able to compare the financial costs of the public bus and rail transport, it is necessary to adjust the starting cost base to comparable cost items.
Only such financial costs can be compared objectively, which individual carriers generate based on clear or same facts or activities (for example Eq. 1).
Total financial costs C_{tot} are described as a sum, given by the following formula (Eq.1):

$$C_{tot} = C_p + C_e + C_{mc} + C_{dv} + C_{om} + C_{infr} + C_o \quad (1)$$

Consisting of: Personnel costs (C_p); Financial costs of energy (C_e); Financial costs of maintenance and cleaning (C_{mc}); Depreciation of transport vehicles (C_{dv}); Financial costs of terminal operation and maintenance (C_{om}); Fee for use of the infrastructure (C_{infr}); Overheads (C_o).

Comparable financial costs C_c

$$C_c = C_p + C_e + C_{mc} + C_{dv} \quad (2)$$

Comparable financial costs are a total of those financial items that are reported by all carriers as necessary expenditures to ensure transport requirements. These include personnel costs, energy costs, costs of maintenance and cleaning, depreciation of transport vehicles and financial costs of terminal operation and maintenance described in both transport modules.

Incomparable cost items C_{ic}

$$C_{ic} = C_{no} + C_{infr} \quad (3)$$

Regional rail transport is, in comparison with bus line transport, loaded with two other fees that increase its operating costs:
Fee for use of the infrastructure (C_{infr});
Costs of operation and maintenance of terminals for bus transportation (for example bus stations and stops) (C_{bs}) will probably be different and lower than similar costs (such as railway station buildings, buildings at stops and station operating staff) (C_{ts}) for railway transport. To balance the difference between both types of costs, we will include only the Cbs costs into the financial costs of the railway transport C_{ts}.
For this reason, to determine comparable cost base, these incomparable costs are deducted at railway transport.

"Adjusted" total operating costs C_{adj}

$$C_{adj} = C_{ic} + C_{res} \quad (4)$$

[2*] Comparable to the line Choceň – Litomyšl or Přelouč – Práchovice.
[3*] Comparable to the line Pardubice – Hradec Králové or Pardubice – Havlíčkův Brod
[4*] Comparable to the corridor lines.

The term “adjusted” total operating costs for this study´s purposes means decreasing railway transport cost items by such items that does not appear in road transport (such as fee for use of the railway infrastructure and levy for renewable electricity sources Cres) or are charged but in significantly lower values (cost of terminal operations). In this case, for the railway transport calculation, we use the cost of terminal operations, but at the same level as for road transport. Such “adjusted” total operating costs in the railway transport are often likened to VLAD costs.
At present, the cost calculation for both types of transport modes is performed without adjusting the differences between these modes, and thus carries elements of mutual incompatibilities.
In terms of railway transport, apart from some other variables, one significant variable also enters into the whole process: lockouts and closures. And precisely this variable often extends the journey time and makes the passengers to change to alternative types of transport (generally buses). And for that reason, it is crucial to eliminate simultaneous closures within one route of long-distance trains (in the Czech Republic such trains are labeled with letter “R” accompanied by a number, for example, R10). (Kamenický; Čermáková; Soušek; Němec, 2011), (Zajíček, 2010), (Soušek; Dvořák, 2015)
In terms of rail transport, however, one particularly crucial variable enters the process, namely line closures and replacement of services. This in itself often prolongs travelling time and forces passengers to change to an alternative means of transport (usually bus). For that reason it is necessary to eliminate simultaneous closures within one long-haul rail route (in the Czech Republic, this is indicated by a capital letter “R” and a number; e.
The distribution of closures occurring at different closure points can then be broken down as follows:

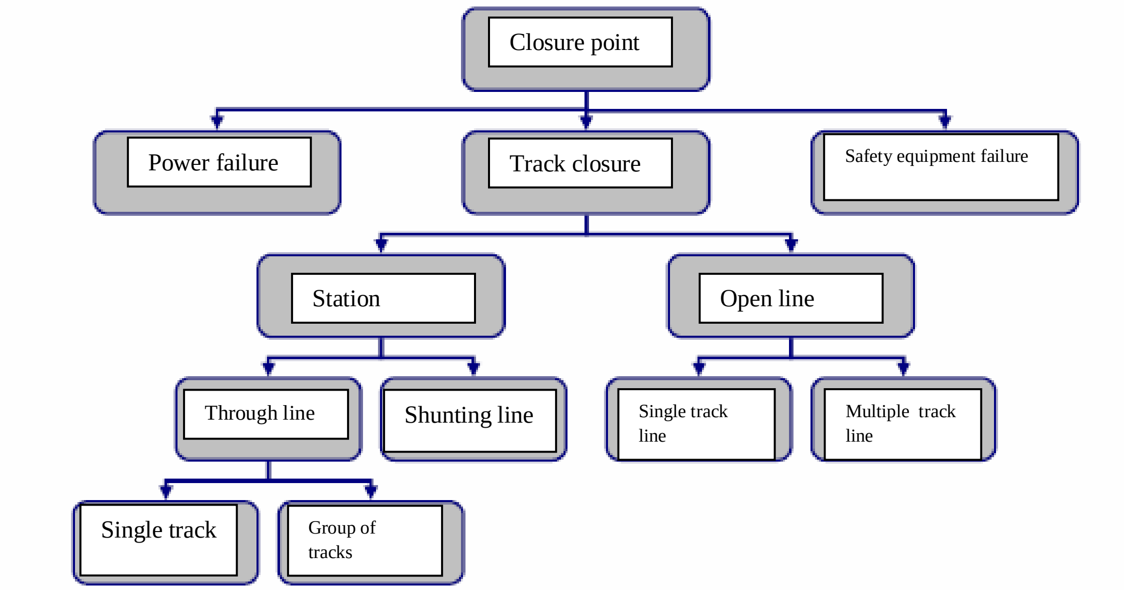


Fig. 1.
Breakdown of closures according to the point of closure

The figure shows that the term “closure” can be applied generally and that its use is varied. However, a power outage will have a different impact on the regularity of rail services than a closure of both tracks on a double track line. When considering the closure point, it must also be taken into consideration whether it is a through line or a shunting track or whether the track in question is occupied or located at a platform at a railway station. As well, the causes are also different. It may be a result of maintenance, repair, refurbishment or upgrading. These latter are often the longest, and usually the most expensive. Maintenance closures deal with the maintenance of a railway line for such purposes as removing vegetation along the track or they may occur during the course of a track inspection when it is necessary to stop regular operations. These closures usually last a few hours or perhaps days, but considering that they are part of a network of transportation, even minor issues have, or may have, an impact on the network infrastructure.
Closures for repairs may last longer. They may last some weeks, and often actually involve part of the railway substructure or superstructure. Examples include the repair of bridges or tunnels on the line, the repair of overhead catenaries or repairs related to the track (reballasting, etc.). Their impact may be considerable, as that section will generally be closed for a longer period of time and in terms of longer term planning (annual plan of closures) it may not be included at all; i.e., the need to close a line for repair may not be known until a relatively short time before it happens.
Closures for refurbishment are closely associated with the idea of “closures for repair”, but usually last longer and are more planned. Refurbishment may mean such operations as the complete replacement of the rails in connection with the construction of an overhead catenary. Its impact is evident given the scale and especially these types of closures must be reflected in the concept of long-term planning of closures in context, as defined in this work. Upgrading closures refer to a complete restoration or extensive reconstruction of a section of track. This includes for example, the extensive upgrade of a railway line through the construction of another parallel track in conjunction with an increase in line speed and the electrification and construction of a rail transit corridor (such as that which took place in 2015 in Úvaly). From

the point of view of the current status, several basic premises generally apply in the Railway Infrastructure **Administration (SŽDC) when planning closures**; particularly:

- Avoiding overlapping closures in order to prevent a train from twice being,
    - ✓ replaced by a bus service during its journey,
    - ✓ diverted, or both diverted and then replaced by a bus service in another part of the route,
- Providing all necessary measures for the timely commencement, suspension and termination of closure work,
- Fully utilising the closure time period,
- Permitting any changes in closures that have already been authorised to take place,
- Restricting closures which require alternative transport during a time of:
    - ✓ Monitored or anticipated transport peaks or at a time of,
    - ✓ Increased transport operation.

Costs of using rail transport routes are reduced proportionately by the untravelled (closed) section, usually in the order of some percents. However, costs increase for the provision of alternative transportation, which for closures of more than about 50 km are higher than the costs of using the transport route. This then creates another fairly substantial financial burden while, according to the operators, passenger numbers fall; hence the organisation of large-scale closures (such as the closure of the Zábřeh – Jesenik line in the Olomouc region in summer of 2016) are very costly and difficult to organise, as shown in the diagram on the previous page.

4. Conclusion

Total financial costs of bus and rail public transport are most strongly influenced by the rates of depreciation of transport vehicles (around 86 %).

A big part is played by the fact that a bus and a railway rolling vehicle have severalfold different buying price as well as a period of service life (factory preset). When using rolling stock at the end of its technical life or even beyond the depreciation line, this provides the railway transport with undull advantage. When using the road and rolling stock with similar purchase years, this, on the other hand, represents a disadvantage for the railway transport due to its higher buying price, which often depends on different technical and safety requirements for road and rail transport vehicles.

In terms of the financial costs of road and railway transport, a very frequent marker and an argument are the value of "total financial costs per km".

Even though it completely ignores the different weight of **transport vehicles used in bus and rail transportation**. Despite the undeniable fact that the weight of rolling stock is usually related to greater transport capacity, its part is also played by legal conditions, which the railway carrier cannot control. The most significant are the safety requirements on the vehicle´s frame structure (according to the Act no. 266/1994 Coll., On Railways and the Regulation no. 173/1995 Coll., which issues the Rules of Railway Operations). Due to this a typical bus Karosa weights around 10 tons when diesel railcar of 810 line weights double. Yet their operational and technical parameters (such as engine, transmission, capacity, etc.) are comparable. It seems that the only objective measure is to relate the economic and technical data to gross tonne-kilometer (grtkm), which would, however, not too objectively favor the railway transport in the end.

Due to the fact, that the main objective of public passenger transport is to satisfy transport needs of the population in a defined territory, the decisive parameter of each vehicle is its transportation capacity. As objective hence could be seen a conversion of operational-technical and economic values per seat of the offered transportation capacity.

For non-electrified tracks, the commissioner, and the railway carriers must have an interest in preferring self-contained motor railcars or motor units of lightweight construction to trainsets consisting of classic passenger railcars pulled by a diesel locomotive.

A road and railway public passenger transport commissioner will always, before preparing and agreeing to new Timetable or before issuing a license to a new carrier, face the decision whether to prefer financial costs or passenger comfort. In the first case, more convenient would be to put into the service “older” vehicles being aware of a possible negative reaction by the public. A very critical moment for the railway transport is the **fleet renewal**. Due to the network characteristics of the railway transportation and long service life of rolling stock, it is important to agree on the highest consistency between the individual commissioners of passenger transport in the public interest. This mainly applies to regional transport. It would be desirable to exclude cases when individual Regional Offices require different types of rolling stock and their requirement is given its weight by contributing to the purchase from their Regional operational programs.

Experiences from Germany on the organization of public passenger transport – a transportation within given region is planned and commissioned by individual federal states, which then act as so-called regional rail transport commissioners. Depending on national legislation, these commissioners become members of organizational structures of transport associations, special-purpose associations, local corporations or respective departments of regional administration. How exactly the regional transport is organized, what types of trains and on which lines will operate, with which transportation capacity, whether they will be manned by an accompanying train staff, all of these parameters are not decided by transport companies such as Deutsche Bahn or their competitors, but by individual commissioners, hence the state governments.

References

Fuchs, P.; Nemec, V.; Sousek, R., Szabo, S., Šustr, M., Viskup, P. 2015. The Assessment of Critical Infrastructure in the Czech Republic. In *Proceedings of the 19th International Scientific Conference on Transport Means*, 418-424.

Fuchs, P.; Zajicek, J. 2013. Safety integrity level (SIL) versus full quantitative risk value, *Eksploatacja i Niezawodnosc*, 15(2): 99-105.

Kamenický, J.; Cermáková, H.; Soušek, R.; Němec, V. 2011. Multiple measurement of physical quantity from the risk evaluation point of view, In *Proceedings of the 15th World Multi-Conference on Systemics, Cybernetics and Informatics*, 212-215.

Sousek, R.; Dvorak, Z., 2013. Methods for Processing Type Threats in Railway Transport. In *Proceedings of the* 17*th International Conference on Transport Means,* 278-281.

Sousek, R.; Riha, Z. 2014. Allocation of Work in Freight Transport. In *Proceedings of the 18th International Conference on Transport Means*, 329-334.

The Ministry of Transport 2013. Transport Bulletin: Information from the Ministry of Transport [cit. 2016-09-10]. Available from Internet: <http://www.mdcr.cz/NR/rdonlyres/1184767E-37D5-4111-BCA0-605F802FFB4B/0/130522_Vestnik_dopravy_11.pdf>.

Zajicek, J. 2010. Analysis and some improvements of FMECA, *Reliability, Risk and Safety: Back to the Future*, 173-177.

IMPACT OF NEW APPROACHES ON THE DEVELOPMENT OF ECONOMIC EVALUATION METHODOLOGY FOR TRANSPORT INFRASTRUCTURE PROJECTS IN THE CZECH REPUBLIC

Vít Hromádka[1], Eva Vítková[2], Petr Vařbuchta[3], Hana Kovářová[4], Lukáš Labudek[5], Michaela Holá[6]

[1,2,3,4,5,6] *Brno University of Technology, Faculty of Civil Engineering, Department of Structural Economics and Management, Brno, Czech Republic*

Abstract: Projects in the field of transport infrastructure form a very important part of public investments in the Czech Republic. For this reason it is essential that only those projects that meet the requirements for achieving economic efficiency and acceptable risk levels should be implemented. Currently, the assessment of economic efficiency and risk management in the Czech Republic are dealt with separately for each fundamental means of transport, i.e. road, rail and water. There is an individual methodology for each of these areas. Each of these methods has worked with characteristics of the specific transport sector in its own evolution. With the newly coming legislation, particularly from the European Commission, there has been a need of transformation of used methodologies specifically into a form that complies with European legislation. The subject of this paper is a detailed analysis of the new requirements for economic evaluation of projects in the areas of road, rail and water infrastructure and comparing them with capabilities of existing methodologies in fulfilment of these requirements. The outcome of the paper has been a list of recommendations leading to the projection of the acquired information into existing approaches to the economic evaluation of projects and the creation of a new comprehensive methodology. The outputs of the paper have been very important arguments for the subsequent discussion about the final form of a new comprehensive evaluation methodology for transport infrastructure projects in the Czech Republic.

Keywords: economic efficiency, transport infrastructure projects, methodology, Czech Republic.

1. Introduction

Transport infrastructure projects represent key strategic projects in any country. In most cases these projects are important not only in terms of the expected impacts on the development of mobility and economy of the state in general, but also from a financial perspective. These projects are very demanding from financial, time and organizational point of view. So it is necessary to carry out only projects sufficiently beneficial for the society. There is usually a national methodology for evaluation of the efficiency of these projects. In the Czech Republic they are currently three methodologies related separately to the road and highway infrastructure, rail infrastructure and water infrastructure which are valid. These methodologies are, however, presently not fully consistent with European Commission requirements stated in the "Guide to Cost Benefit Analysis of Investment Projects" document. For this reason, one of the goals of the Ministry of Transport of the Czech Republic is to create a uniform methodology for evaluating the economic efficiency of projects across all transport infrastructures.

The paper is particularly focused on identifying the fundamental differences between the currently valid approaches and methodology of the European Commission, on the assessment of the impacts of these differences on economic evaluation of projects and on formulation of recommendations for carrying out a new comprehensive methodology for evaluation of infrastructure projects in the Czech Republic.

2. Present state references

Investment projects in transport infrastructure are very important both for the population of the country and general economic growth of the national economy. New or modernized transport infrastructure brings new business opportunities to individual regions; it accelerates and simplifies the transportation of productive factors and results of the production itself. Besides the impact on businesses entities, it is necessary to emphasize also the significant impacts on the population providing diverse, faster and safer transportation options. According to the fact that in most cases the projects are very costly from the investment point of view and moreover financed from public sources, it is important to evaluate not only the factual side of the projects, but also their economic aspects.

One of the basic objectives of the allocation of public resources is respecting the 3E principle (Economy, Effectiveness and Efficiency) in their whole life cycle. Economy refers to efforts to minimize especially financial resources. Efficiency indicates the use of such resources, which enable to achieve maximum volume and quality of products. In the course of economic evaluation of investment projects in the area of transport infrastructure, it is essential to respect the minimal amount of impacts of a certain project on the society. Economic impacts are usually grouped into (a) direct economic benefits, i.e. economic costs and benefits directly related to the project, where travel-cost savings form typically the most important (user) benefit category for infrastructure projects, and (b) indirect economic benefits, the (wider) economic effects not directly related to the project but resulting from the direct impacts, e.g. productivity gains of firms and distributional effects (Geurs & van Wee, 2004). Among socio-economic impacts of transport projects are also included: environmental impacts e.g. pollution or noise (Thanos, Wardman & Bristow, 2011), (Browne & Ryan,

[1] Corresponding author: hromadka.v@fce.vutbr.cz

2011), benefits to the natural habitat (Oxman, Lavis, Lewin & Fretheim, 2009), visual intrusion, health impacts (Thomopoulos & Grant-Muller, 2013), settlement cohesion, accessibility, land use planning, agglomeration, labour displacement and habitat fragmentation and equity (Mancebo Quintana & Martin Ramos, 2010).

Cost Benefit Analysis (CBA) is an appropriate method for assessing the economic efficiency of public projects generating particularly non-financial benefits. Use of CBA is emphasized by various authors, e.g. (Mackie, Worsley, & Eliasson, 2014), (Hyard, 2012), (Jones, Moura & Domingos, 2014), (Damart& Roy, 2009) and (Jajac, Marović & Hanák, 2014). A more detailed analysis of the benefits of investment projects in road infrastructure has been already published in the article by Korytárová & Papežíková, (2015).

In the Czech Republic the methodological materials to assess the economic efficiency of projects in the field of transport infrastructure based on CBA principle have already existed. Methodology called “The implementing instructions for evaluating the economic effectiveness of projects of road and motorway construction” by the Road and Motorway Directorate of the Czech Republic (RSD CR, 2014) is used for the projects of road and highway infrastructure, methodology called “The implementing instructions for evaluating the economic effectiveness of projects of railway infrastructure” by the Ministry of Transport of the Czech Republic (MOT CR, 2013) is used for railway infrastructure projects and “The implementing instructions for evaluating of the economic effectiveness of projects on water ways” methodology by Ministry of Transport of the Czech Republic (MOT CR, 2005) is used in the case of important transport projects in water infrastructure.

As mentioned above, these methodological materials are based on the CBA principles, but in some parts do not meet the requirements demanded for CBA analysis processing, defined by the “Guide to Cost Benefit Analysis of Investment projects” by European Commission (Sartori, 2014). The subject of this paper is to identify selected differences and to specify in detail the impacts of potential changes in the methodologies on the economic evaluation of the projects of transport (especially road and highway) infrastructure.

3. Methodology

The basic methodological approach used in the research is the analysis of differences between approaches to economic evaluation of transport infrastructure projects in the Czech Republic currently used according to the valid documentation and the approaches recommended based on the appropriate documentation of the European Commission. As the results are suggested recommendations for possible changes to already existing implementation documentation and depiction of impacts of potential changes on the evaluation results. This depiction has been carried out using a further methodological tool: a case study. The key differences between already existing state of economic evaluation of transport infrastructure projects in the Czech Republic and modification of the relevant documents suggested by the European Commission have been identified as the first step of the case study. Subsequently the impacts of potential changes to the evaluation of economic efficiency of the project have been quantified on example of the real traffic infrastructure construction in the Czech Republic.

Within the case study, the principles of Cost-Benefit Analysis (CBA) based on the calculation of the Net Present Value of economic flows in the project and sensitivity analysis based on the assessment of the resistance of the project against changes in the key input variables have been subsequently applied.

The paper is focused mainly on the economic evaluation of projects of road and highway infrastructure according to the fact that most changes are expected in the area of economic evaluation of this type of projects.

4. Results and discussion

Economic evaluation of road and highway infrastructure projects in the Czech Republic have currently been dealt with using "The Implementing Instructions for Evaluating the Economic Effectiveness of Projects of Road and Motorway Construction" by the Road and Motorway Directorate of the Czech Republic (RSD CR, 2014). Due to the requirements put on the economic analysis resulting from the European Commission document "Guide to Cost-Benefit Analysis of Investment Projects" (Sartori, 2014), the interim methodology reflecting certain requirements from the above mentioned document of the European Commission, supplementing existing national methodology, has been prepared. This methodology will be valid until a new common methodology for road, rail and water transport will have been approved.

It can be stated based on the analysis of relevant documents carried out that fundamental difference between the existing and the desired methodologies can be found in the following areas:

- Evaluated period,
- Discount rate,
- Investment costs,
- Performing qualitative and quantitative risk analysis,
- Assessed values in the frame of the sensitivity analysis,
- Residual value of the project,
- Conversion factor.

Evaluated period

According to existing documentation, projects are evaluated for the period including the investment phase and thirty years of operation. According to the requirements arising from documents by the European Commission, the considered evaluated period should be thirty years in total including both investment and operating phase of the project.

Discount rate

Compared to the existing regulation, the financial discount rate is reduced from 5% to 4% and economic discount rate from 5.5% to 5%.

Investment costs

In the current economic evaluation of investment projects, only the costs of the construction work carried out are considered within this category according to the new regulation, investment costs include costs related to the purchase of land as well as.

Residual value of the project

In the existing documentation, a residual value of the project assessment is based on the financial value of the acquired property, when the final residual value of each types of purchased property depends on its purchase price and durability beyond the evaluation period. According to the new requirements, the residual value should be determined on the basis of expected cash flows from the investment after the end of the evaluated period to reach average lifetime of the assets acquired by the project (determined by weighted arithmetic average of lifetimes of individual types of property where the weights are the investment costs).

Assessed values in the frame of the sensitivity analysis

According to the current practice, sensitivity analysis of projects of road and highway infrastructure is carried out for a change in construction costs and for a change in the overall user benefits. According to the new regulations, sensitivity analysis should be more detailed and among the assessed values should be, besides investment costs, also partial benefits (time value, cost of accidents) and the expected development of transport intensity or number of years of construction.

Performing qualitative and quantitative risk analysis

According to the current practice, only sensitivity analysis including the determination of "overlap" values of assessed variables is carried out in the frame of the risk analysis. Newly, a detailed qualitative risk analysis covering their determination and definition, determining their probability and degree of impact and description of potential measures to reduce or eliminate the risks, should be carried out. A quantitative analysis of key risk factors using mathematical simulations with Monte-Carlo method should be also implemented.

Conversion factor

Conversion is used in economic analysis. This is a transfer from the financial analysis to the economic analysis. The economic analysis evaluates how the project contributes to changing the level of prosperity, and therefore it is important to use shadow prices that represent the social opportunity costs of goods and services. Conversion factor has not been used up to now for evaluation of projects of road and highway infrastructure, however, the inputs into economic analysis have been considered without VAT.

4.1. Case study

The impact of some of the above mentioned changes on the overall evaluation of the project has been demonstrated by a case study. The case study has been carried out on the project of the new construction of “Southern Conjunction” - a section of four-lane capacity road of citywide importance which represents a new capacitive connection between D11 motorway and the centre of Hradec Kralové city in the Czech Republic. The basic design category of “Southern Conjunction” is MS4d 19/70. Communication has two opposite direction lanes separated in the middle by 3.0 meters wide centre lane. The design speed of “Southern Conjunction” is 70 km/h., from which horizontal and vertical lines are derived. Total length of the main route is 2.96 km and the estimated investment costs are 1,609,963 thousand CZK (59,628 thousand EURO) without VAT. Data for carrying out the case study were taken from the study evaluating the efficiency of the project (AF-CityPlan, 2015). General situation of the project is displayed in Fig. 1.

Fig. 1.
Project I/11 – I/37 Southern Conjunction Hradec Králové – general situation
Source: own work using mapy.cz server

The basic input data for the economic assessment in actual and new approaches is shown in Table 1.

Table 1
Input data for the economic assessment

Input variables	**Actual approach**	**New approach**
Duration of investment phase (years)	3	3
Duration of operational phase (years)	30	27
Total duration of evaluated period (years)	33	30
Residual value assessment	residual value of property according to the lifetime	discounted cash-flows till reaching the average lifetime of the property
Investment costs (1,000 EURO without VAT)	59,628	59,628
Discount rate	5.5%	5%

Source: own work according to the project study (AF-CityPlan, 2015)

It is evident from Table 1 that in comparison of the calculation of economic efficiency according to the actual and new approaches, the changes in determining the length of the evaluation period, residual prices and a change in the discount rate have been taken into account. However, the change in the determination of investment costs, regarding the current uncertainties arising from determining the economic value of purchased land has not been considered.

The final values of economic indicators calculated both using actual and new approaches are shown in Table 2.

Table 2
Values of economic indicators

Indicator	**Actual approach**	**New approach**
Net Present Value (NPV)	1,851 mil. EURO	10,497 mil. EURO
Internal Rate of Return (IRR)	5,72%	6,09%
Benefit Cost Ration (BCR)	1.034	1.182

Source: own work according to the project study (AF-CityPlan, 2015)

Materials to make the calculations were taken from the project study (AF-CityPlan, 2015).
The results of the case study show that in the case of evaluated project, the considered combination of changes has had a positive impact on the economic evaluation and the economic results of the project are within the new approach more favourable for the project despite shortening of the length of the evaluation period. Different results can be, however, expected especially in the case of projects with a longer investment phase. In the case of large projects (some projects in the Czech Republic have expected length of the construction process up to 17 years) it is possible to expect more significant impact of the shortening of the evaluated period, even so it can be to some extend compensated (but at the same time distorted) by a new method for determining the residual value.

In the frame of the case study, the sensitivity analysis processing according to the current practice and the new approach have been compared. According to current practice, the sensitivity analysis has been carried out for two input variables - construction costs and overall benefits. In the case study, these input variables have been supplemented by partial benefits within the new approach. The results of the supplemented sensitivity analysis for the evaluated project are shown in Figure 2.

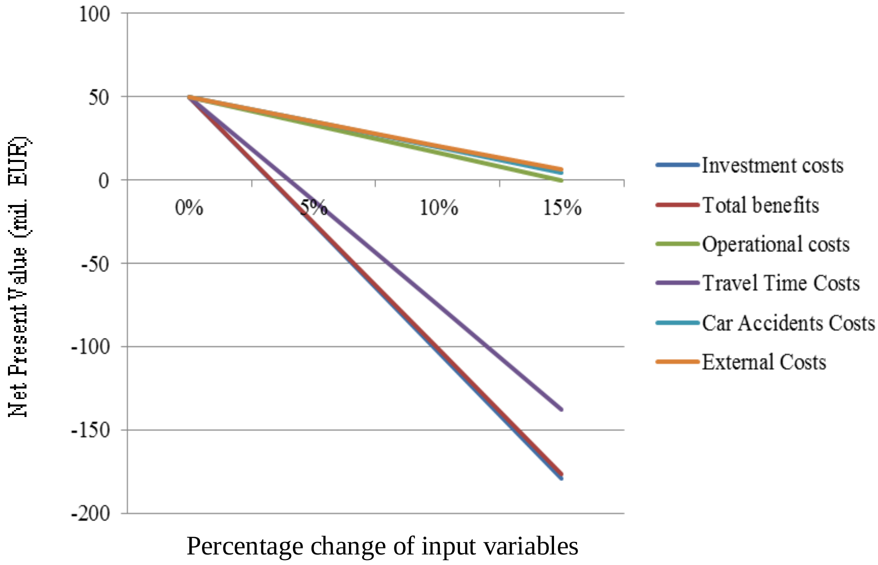


Fig. 2.
Sensitivity analysis – dependence of project NPV on percentage change in input variables
Source: own work according to the project study (AF-CityPlan, 2015)

Figure 2 shows the relationship between the percentage change of the input variables (benefits and costs) and Net Present Value of the project. For illustrative purposes the percentage change is defined in such way that it decreases the final Net Present Value (in the case of the benefits, the change in negative, in the case of the costs, the change is positive). Material for the calculation of the sensitivity analysis has been taken from the project study (AF-CityPlan, 2015).

4.2. Discussion

The subject of this paper is the analysis of the way of the current economic evaluation of the projects of road and highway infrastructure in comparison with changes in the economic evaluation resulting from the need of implementation of the principles stated by the new European Commission documents. As a part of the introduction to this chapter, following significant areas of changes in the economic evaluation have been identified:

- Evaluated period,
- Discount rate,
- Investment costs,
- Performing qualitative and quantitative risk analysis,
- Assessed values in the frame of the sensitivity analysis,
- Residual value of the project,
- Conversion factor.

Duration and structure of the evaluated period, discount rate and the residual value of the investment are relatively clear areas with easy implementation from a methodological point of view. First part of the case study presented in this paper brings an example of the impact of changes in these variables on the calculated efficiency of the evaluated project. In the case study, the impact of changes is rather positive; the project appears to be more efficient than in the case of usage of the already existing approach. However, this conclusion cannot be generalized, since the duration of construction and therefore duration of the evaluated part of the operating phase with the constant length of the evaluation period of 30 years including both investment and operational phases will play a significant role.

Investment costs should include expenses related to the purchase of property according to new approach. In terms of methodology, it is a correct decision. However, the problem lies in determining of the economic (shadow) costs associated with this acquisition. The final purchase price is often several times higher than the estimated price or a price determined according to the price map, and is often significantly influenced by the exaggerated requirements of the owners. In this respect, it is possible to formulate recommendations for the creation of a new methodology, which consists in creation of a procedure for determining the economic (shadow) prices of purchased pieces of property

showing the actual detriment for the society by their use in the road infrastructure, e.g. at the level of values listed in the price maps or at prices determined by an expert according to the corresponding legislation.
In the risk analysis of investment projects in the road and highway infrastructure, only a sensitivity analysis evaluating the impact of changes in investment costs and changes in total benefits on the evaluation criteria has appeared so far. Within the sensitivity analysis, a more detailed sensitivity analysis covering the assessment of impacts of the effects of changes to partial benefits or changes to the intensity of traffic may be recommended in accordance with the relevant documentation. Sensitivity analysis supplemented by more detailed assessment of impacts of partial benefits is the subject to the second part of the case study presented in this paper. Following the results of the sensitivity analysis, paying more attention to those inputs for which a high degree of sensitivity has been found (in the case study they are mainly the costs of travel time) can be recommended.
Following the sensitivity analysis, further steps can be recommended. Such key step can be the determining of critical variables (their description should be clearly defined in the methodology) further tested within the recommended mathematical simulation using Monte-Carlo method. Part of the risk analysis should also be a qualitative risk analysis comprising their identification including description, determining of their significance (probability of occurrence and intensity of the negative impact on the project) and the description of the measures for their reduction or elimination.
The last monitored area has been the conversion factor issue. Conversion factors should not be calculated for each project separately, they should be included in the national methodology. For a specific project they should be calculated only if the national parameters are not available. It is therefore possible to recommend the formulation of conversion factors within the frame of the arising general national methodology. Taking conversion factor into account will be particularly important in determining the investment costs (shadow prices of purchased property and the cost of the construction itself).

5. Conclusion

The subject of this paper was a detailed analysis of new requirements for economic evaluation of projects in the areas of road, rail and water infrastructure, and to compare them with capability of existing methodologies to fulfil these requirements. The outcome of the paper is a list of recommendations leading to the projection of the acquired information into existing approaches to economic evaluation of projects and formation of a new comprehensive methodology. The paper is particularly focused on the evaluation of economic efficiency of projects in the road and highway infrastructure. In the introductory part of the paper, an analysis of the current state in order to identify the available literature sources covering the above-mentioned issue has been carried out. Subsequently the methodology of processing the research has been briefly introduced. The essential part of the paper is represented by the fourth chapter, where the key changes in the evaluation of economic efficiency of projects in the road and highway infrastructure caused by new requirements by the European Commission have been identified and described. In the case study, the effects of these changes on the resulting economic evaluation of projects and their interpretation have been tested. Mainly the changes to the structure and length of the evaluation period, the discount rate, calculating of the residual value of the project and changes to the risk assessment using sensitivity analysis have been tested. The recommendations arising from the conclusions of the analysis and case study for the purpose of creating of the new general methodology for the evaluation of transport infrastructure projects in the Czech Republic have been subsequently formulated in the discussion.

Acknowledgements

This paper has been worked out under the project of the specific research at Brno University of Technology no. FAST-S-16-3556 Management of economic processes in the sub-phases of the life cycle of buildings.

References

AF-CityPlan 2015. *I/11 – I/37 Southern Conjunction Hradec Králové*. Economic Efficiency Valuation.
Browne, D.; Ryan, L. 2011. Comparative analysis of evaluation techniques for transport policies, *Environmental Impact Assessment Review*, 31(3): 226-233.
Damart, S.; Roy, B. 2009. The uses of cost-benefit analysis in public transportation decision-making in France, *Transport Policy*, 16(4): 200-212.
Geurs, K. T.; Van Wee, B. 2004. Accessibility evaluation of land-use and transport strategies: review and research directions, *Journal of Transport Geography*, 12(2): 127-140.
Hyard, A. 2012. Cost-benefit analysis according to Sen: An application in the evaluation of transport infrastructures in France, *Transportation Research Part A: Policy and Practice*, 46(4): 707-719.
Jajac, N.; Marović, I.; Hanák, T. 2015. Decision support for management of urban transport projects, *Gradevinar*, 67(2): 131-141.
Jones, H.; Moura, F.; Domingos, T. 2014. Transport infrastructure project evaluation using cost-benefit analysis, *Procedia - Social and Behavioral Sciences*, 111: 400-409.
Korytárová, J.; Papežíková, P. 2015. Assessment of Large- Scale Projects Based on CBA // In ProjMAN - International Conference on Project MANagement, *Procedia Computer Science*, 64: 736-743.

Mackie, P.; Worsley, T.; Eliasson, J. 2014. Transport appraisal revisited, *Research in Transportation Economics*, 47(1): 3-18.

Mancebo Quintana, S.; Martin Ramos, B.; Casermeiro Martinez, M.; Otero Pastor, I. 2010. A model for assessing habitat fragmentation caused by new infrastructures in extensive territories, *Journal of environmental management*, 91(5): 1087-1096.

Ministry of Transport of the Czech Republic (MOT CR). 2013. The implementing instructions for evaluating the economic effectiveness of projects of railway infrastructure. Available from Internet: <http://www.mdcr.cz/>.

Ministry of Transport of the Czech Republic (MOT CR). 2005. The implementing instructions for evaluating of the economic effectiveness of projects on water ways. Available from Internet: <http://www.mdcr.cz/>.

Ochrana, F.; Jan, P.; Vítek, L. 2010. *Veřejný sektor a veřejné finance, Financování nepodnikatelských a podnikatelských aktivit (Public sector and public finance, financing of non-business and business activities)*, Grada Publishing, a.s., Praha, Czech Republic.

Oxman, A.; Lavis, J.; Lewin, S.; Fretheim, A. 2009. Support tools for evidence informed health policymaking (STP) 10 // Taking equity into consideration when assessing the findings of a systematic review, *Health Research Policy and Systems*, 7(1): 1-9.

Road and Motorway Directorate of the Czech Republic (RSD CR). 2014. The implementing instructions for evaluating the economic effectiveness of projects of road and motorway construction. Available from Internet: <http://www.rsd.cz/doc/Technicke-predpisy/HDM-4/provadeci-pokyny-pro-hodnoceni-ekonomicke-efektivnosti-projektu-silnicnich-a-dalnicnich-staveb>.

Sartori, D. 2014. *Guide to Cost-benefit Analysis of Investment Projects, Economic appraisal tool for Cohesion Policy 2014-2020*. European Commission, Directorate-General for Regional and Urban policy.

Thanos, S.; Wardman, M.; Bristow, A. 2011. Valuing aircraft noise; Stated Choice experiments reflecting inter-temporal noise changes from airport relocation, *Environmental and Resource Economics*, 50(4): 559-583.

Thomopoulos, N.; Grant-Muller, S. 2013. Incorporating equity as part of the wider impacts in transport infrastructure assessment: an application of the SUMINI approach, *Transportation*, 40(2): 315-345.

IMPACT OF LIBERALIZATION OF FOREIGN TRADE ON THE SERBIAN ROAD FREIGHT TRANSPORT SECTOR

Olivera Medar[1], Jelica Petrović Vujačić[2], Marko Miljković[3]
[1,2,3] University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, Belgrade, Serbia

Abstract: The process of trade liberalization in Serbia since the year 2000 went in several directions. The most important of these are in the areas in which Serbia has the largest volume of trade that is countries of the European Union (EU), countries of the Western Balkans region and the Russian Federation. On January 1st 2014 Serbia came into the sixth and final year of trade liberalization with the EU on the basis of the Stabilization and Association Agreement (SAA). In December 2006, the countries of the Western Balkans signed the Central European Free Trade Agreement (CEFTA), which substituted a network of bilateral free trade agreements. The countries remaining in CEFTA are: Albania, Bosnia and Herzegovina, FYR Macedonia, Montenegro, Serbia, UNMIK-Kosovo and Moldova which make up for a common market of close to 23 million consumers. The paper analyzes the influence of foreign trade liberalization on the Serbian road freight transport sector with special focus on haulers. International road freight transport input (vehicle purchase) and output (tones carried or tone-km performed) follow closely the demand cycle of the economy (GDP) in general and trade (exports) in particular. Dropping demand during financial crises in 2008 caused a contraction of haulage (million tons). In economic as well as road transport related literature the term of liberalization or deregulation is often used to describe the process of facilitating or improving conditions of operations for economic entities in road transport, that is, haulers. Transport, in particular international road freight transport, has always been regulated for justified reasons such as the need for safety, security, technical harmonization. The paper gives special attention to the effects of specific types of permits and quotas on transport flows and flows of goods.

Keywords: foreign trade liberalization, road freight transport sector, Serbia.

1. Introduction

Since the middle of the 20th century, when the General Agreement on Tariffs and Trade (GATT) was created, the world trading system has benefited from various rounds of multilateral trade liberalization, as well as from unilateral and regional liberalization. The economic literature suggests that there is no country in recent decades which has achieved economic success, in terms of substantial increases in living standards for its people, without being open to the rest of the world (IMF, 2001). OECD (2011) emphasizes that further opening of trade can stimulate economic growth, job creation, as well as higher real wages for workers.

The process of significant trade opening in Serbia started at the beginning of the 21st century and went in several directions. The most important of these are in the areas in which Serbia has the largest volume of trade that is countries of the European Union (EU), countries of the Western Balkans region and the Russian Federation. On January 1st 2014 Serbia came into the sixth and final year of trade liberalization with the EU on the basis of the Stabilization and Association Agreement (SAA). In December 2006, the countries of the Western Balkans signed the Central European Free Trade Agreement (CEFTA), which substituted a network of bilateral free trade agreements. The countries remaining in CEFTA are: Albania, Bosnia and Herzegovina, FYR Macedonia, Montenegro, Serbia, UNMIK-Kosovo and Moldova which make up for a common market of close to 23 million consumers. Additionally, Serbia liberalized its trade with the Russian Federation, Belarus, Kazakhstan, EFTA countries, Turkey, as well as with USA under General System of Preferences, which makes a duty-free market for exports of more than one billion people.

On the other hand, market access has been reduced by a series of obstacles arising from the existing permit quotas for bilateral, transit and cross-trade transport operations. The transport permits make it very difficult, if not impossible, to operate in certain markets, they complicate the organization of transport processes, reduce work efficiency and create additional costs for the hauliers and users alike. The permit quotas include CEMT permits issued to the Serbia within the multilateral system of quotas, and bilateral permits exchanged between the Republic of Serbia and other states. The number of permits available to Serbian hauliers, which are distributed by the competent authority, does not correspond to their needs. The insufficient quotas are the result of many things, including a very restrictive approach the other states have taken to protect national hauliers or the environment; a focus of interest in another field; poor negotiations or even the total lack of engagement by national authorities in this respect. More often than not the status and needs of the market change too rapidly for the national authorities to react (Medar & Manojlović, 2011).

2. Foreign trade dynamics of Serbia: contribution of trade liberalization

Serbian economy is characterized by continuously high values of the deficit in external trade in goods. In 2015 the deficit amounted to EUR 4.3 billion and it declined as compared with previous years. The structure of Serbian external trade by products is also unfavourable. Products at lower levels of processing, primarily raw materials and semi-finished goods, possess the dominant share in the structure of Serbian exports. On the other hand, capital goods and energy, which generate quite higher value, have a significant share in the structure of imports, in addition to non-durable consumer goods. In Table 1, there are presented values and volume of exports, imports and foreign trade balance of Serbia during the last ten years.

[1] Corresponding author: o.medar@sf.bg.ac.rs

Table 1
Exports, imports and foreign trade balance of Serbia in the period 2006-2015

Year	Value in EUR million			Volume in thousand tonnes	
	Exports	Imports	Trade balance	Exports	Imports
2006	5,116.8	10,485.7	-5,368.8	8,345.2	15,225.3
2007	6,437.9	13,535.4	-7,097.5	9,463.7	16,497.5
2008	7,457.2	15,547.3	-8,090.1	9,537.9	17,043.0
2009	5,983.7	11,506.6	-5,522.9	8,708.3	13,363.9
2010	7,376.0	12,602.4	-5,226.3	10,318.5	14,092.4
2011	8,457.2	14,260.1	-5,802.9	10,697.6	13,963.8
2012	8,731.2	14,715.1	-5,983.9	10,399.9	12,085.2
2013	11,000.0	15,472.2	-4,472.2	11,175.8	12,127.3
2014	11,166.7	15,504.0	-4,337.2	11,415.1	13,080.1
2015	12,053.2	16,405.6	-4,352.5	11,626.0	15,445.0

Source: Trade Map Statistics Database, SORS Database

The most important exporting markets for Serbia are European Union member countries, primarily Germany, Italy and Austria, which made almost two thirds of value of Serbian exports in 2015. The second largest foreign trade partner are CEFTA member countries, which Serbia continuously achieves high amounts of trade surplus with. The detailed structure of exports by countries, Serbia has free trade agreements with, is presented in the Figure 1.

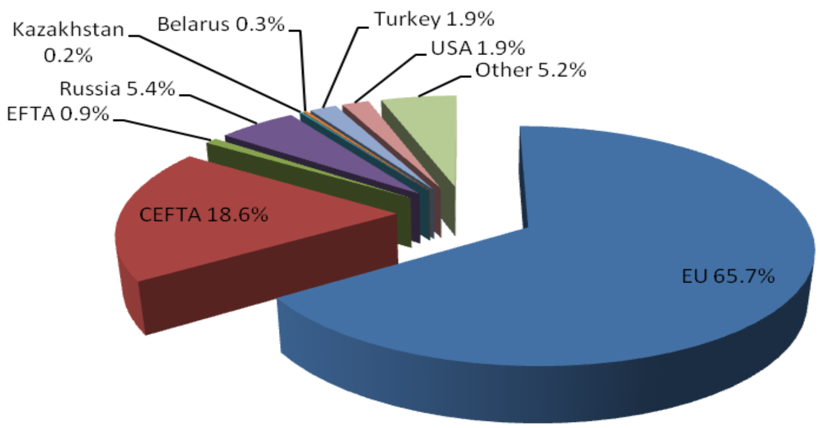


Fig. 1.
Structure of Serbian exports by exporting markets in 2015
Source: Trade Map Statistics Database

Liberalization of trade contributed significantly to growth of exported values, what is presented in Table 2. The best indicator of such a contribution is the value of exports growth in the year of trade liberalization. For example, in the year when free trade agreements came into force, the value of exports to Turkey (in 2011), Belarus and Kazakhstan (in 2010) more than doubled. Significantly high growth rates of exports value achieved in the first year of trade liberalization with Switzerland (28.4% in 2011) and CEFTA countries (35.4% in 2007). The only one exception is related to European Union, considering the first and strongest wave of global economic crises which occurred in 2009 and which significantly affected aggregate demand level in EU member countries. However, the averaged data on exported values before and after Stabilization and Association Agreement do indicate the positive contribution of trade liberalization with EU. There are also presented average values of exports, as well as average growth rates of exports in the period before trade liberalization (after 2006), as well as after trade liberalization (till 2015). Significantly higher growth rates of exports were recorded after the trade openings, up to ten times higher growth rates.

Table 2
Effects of trade liberalization on Serbian exports in the period 2006-2015

Group of countries	Year of trade liberalization	Exports value growth in the year of liberalization	Average value of exports, EUR mil.		Average growth rate of exports	
			Before liberalization	After liberalization	Before liberalization	After liberalization
European Union	2009	-21.4%	3,826.2	6,521.8	11.8%	12.6%
CEFTA countries	2007	35.4%	n.a.	1,925.3	n.a.	6.8%
Switzerland - EFTA	2011	28.4%	50.1	72.9	10.6%	12.4%
Russia	2001	n.a.	n.a.	507.4	n.a.	14.9%
Turkey	2010	104.8%	34.2	151.0	5.2%	43.6%
Kazakhstan	2011	105.6%	6.2	11.9	6.7%	49.6%
Belarus	2010	115.9%	11.6	45.4	8.4%	24.5%

Source: Calculation of authors based on data from Trade Map Statistics Database

3. Impact of trade liberalization on Serbian road freight transport sector

Road freight transport is a dominant mode of international transport in Serbia. Comparing data published by Statistical Office of the Republic of Serbia (SORS) for external trade, exports and imports, in the SORS Statistical Database to the data for road transport from SORS Statistical Releases “Entry, exit and transit of freight road vehicles” for the period 2004-2015 the international transport of goods by road (transit excluded) was almost twice as large as transport by other modes of transport, measured in transported tonnes (Fig. 2). Serbian hauliers are the most active, representing over one half of total performance (in tonnes) (Fig. 3). More than 30% of foreign hauliers are from Bosnia and Herzegovina, followed by hauliers from Montenegro (~15%), FRY Macedonia (~10%), Croatia (~7%), and Slovenia (~6%) – the hauliers from ex-Yugoslavia republics dominate between foreign hauliers. The Bosnian hauliers aside, those from the states that are involved in a large-scale external trade (Italy and Germany for instance) do not have an adequate share in Serbia’s international road transport market. This market is not attractive to them due to too many obstacles during transport operations.

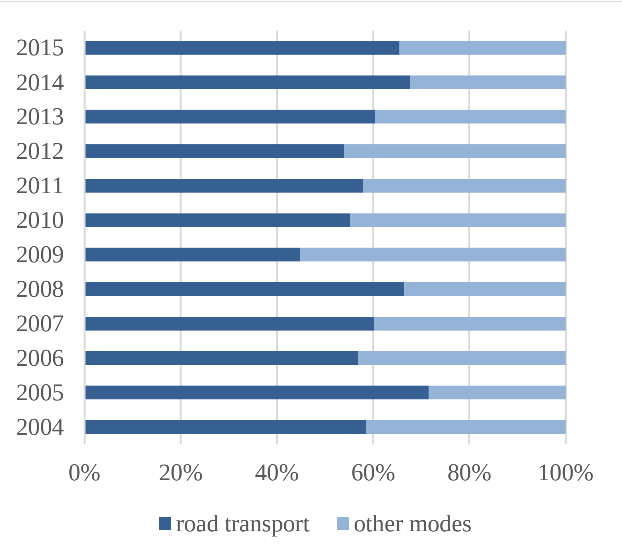


Fig. 2.
Road transport share in total exports (based on tonnes) [%]
Source: Calculation of authors based on SORS Statistical Database and Statistical Releases SV31

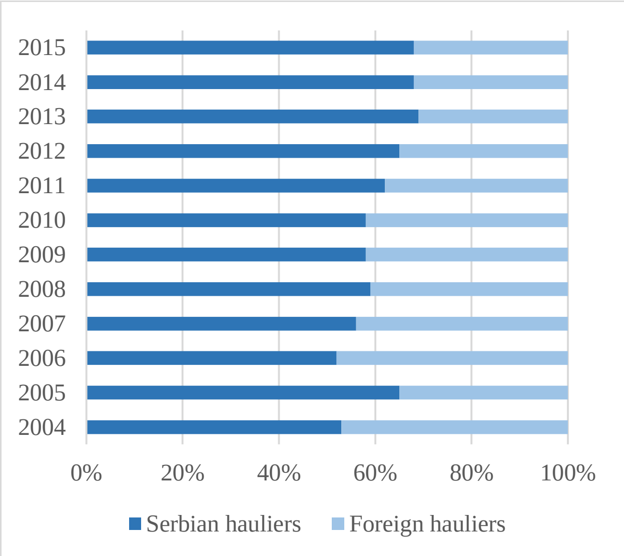


Fig. 3.
Share in international road freight transport by the haulier’s nationality (exports, based on tonnes) [%]
Source: Calculation of authors based on SORS Statistical Releases SV31

In Serbia, in 2000, at the time when political changes have started, there were around 350 hauliers[2] performing the international road transport operations. For the purposes of this paper, Serbian hauliers involved in international road transport of goods include the hauliers that have met the legal conditions for admission to the occupation of road haulage operator, and perform the activity continually over the year. These include the hauliers that participate in the annual distribution of foreign and multilateral permits (Annual Permit Distribution Plan). There is an irrelevant number of other hauliers, whose involvement in international road transport is sporadic, and mostly for their own account, or in a limited market only. From the end of 2000 until 2003 the number of has grown for about 50%, around 450 hauliers, at the biggest growth rate till today. In the following years this growing trend continued with a lower rate and at the end of 2008 the number of hauliers was more than doubled (Fig. 4), amounted around 770 hauliers. Then, the number dropped during the period of the global economic crisis, and after 2012 the recovery trend can be seen, with 902 hauliers at the end of 2015 having on average 10.5 vehicles and 12 drivers (Fig. 5). The number of hauliers is not too big due to legal provisions in force: international road transport can be operated only by domestic company (legal person), and a large number of entrepreneurs are deprived of performing the activity of international road transport. This situation will be changed in 2017 when new provisions enter in force.

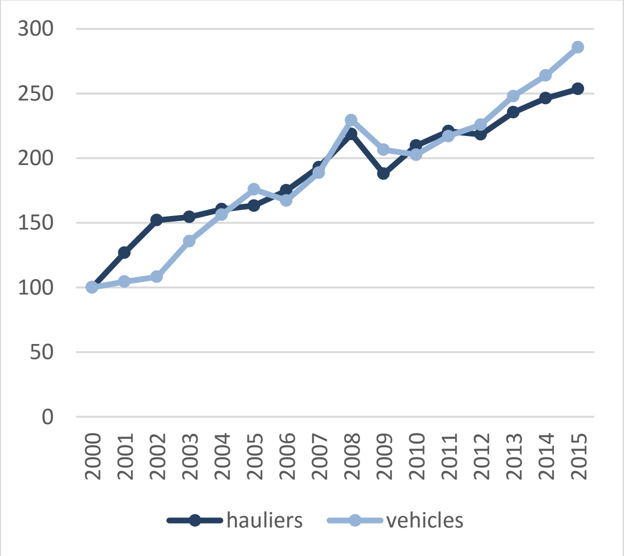


Fig. 4.
Number of hauliers and drawing vehicles (lorries and road tractors), Indexes 2000-2015 (2000=100)
Source: Calculation of authors based on MCTI Annual Permit Distribution Plan

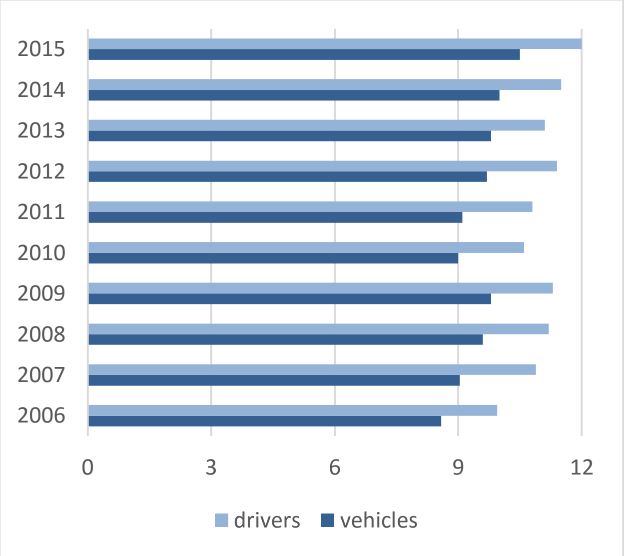


Fig. 5.
Average vehicle fleet size and average number of employed drivers, 2006–2015
Source: Calculation of authors based on MCTI Annual Permit Distribution Plan

During the same period, 2000-2015, the number of drawing vehicles (lorries and road tractors) was raised a little bit faster, with almost 10,000 vehicles at the end of 2015 which is the number nearly tripled comparing to 2000. Similar trends to number of haulier have been noted for number of vehicles (Fig.4). Apart from the increase of vehicles in numbers, the fleet structure have been changed significantly in favour of environmentally friendly vehicles (Fig. 6). This purchasing strategy is confirmed also with data on average fleet size which remain around 9 vehicles over long period (Fig. 5). Purchasing of vehicles meeting emission, noise and safety standards were motivated above all by the possibility of overcoming severe market access barriers for Serbian hauliers (quotas of bilateral and ECMT permits). The 2007 research (*Medar and Manojlović*, 2011) showed that the permits motivated 69.2% hauliers to buy better vehicles because they have been aware that any addition to the existing quotas was only possible by reshaping fleet structure in favour of environmentally friendly vehicles. In the years 2007 and 2008 Serbian hauliers purchased almost 1,000 new vehicles manufactured the same year (Fig. 7). The average age of road tractors in 2008 was at the lowest level – 5.8 years.

[2] For the purposes of this paper, Serbian hauliers involved in international road transport of goods include the hauliers that have met the conditions for admission to the occupation of road haulage operator, as defined by the national legislation and perform the activity continually over the year; these include the hauliers that participate in the annual distribution of foreign and multilateral permits (Annual Permit Distribution Plan), which grant them access to the international road haulage market. There is an irrelevant number of other hauliers, whose involvement in international road transport is sporadic, and mostly for their own account, or in a limited market only.

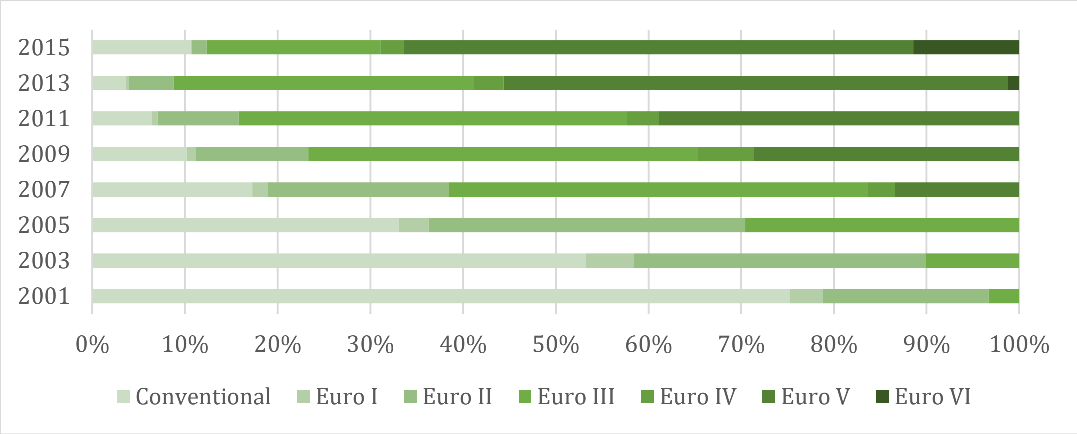


Fig. 6.
Fleet structure by environmental class, 2001–2015
Source: Calculation of authors based on MCTI Annual Permit Distribution Plan

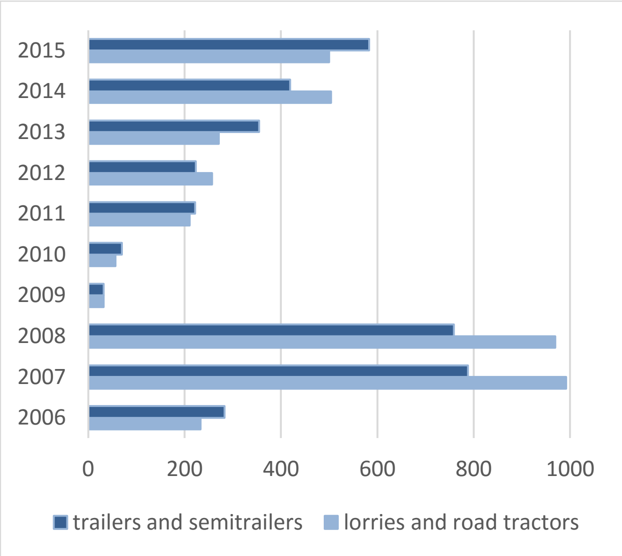


Fig. 7.
Number of purchased new vehicles, manufactured in the year of observation, 2006-2015
Source: Calculation of authors based on MCTI Annual Permit Distribution Plan

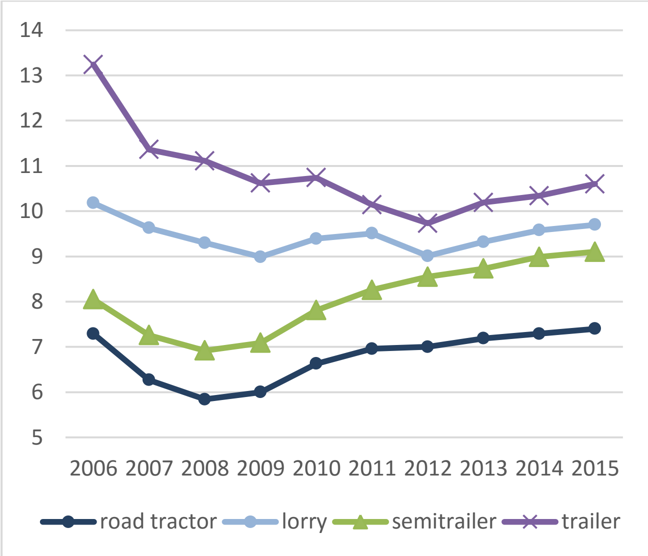


Fig. 8.
Average age of vehicles [years], 2006-2015
Source: Calculation of authors based on MCTI Annual Permit Distribution Plan

3. Quota of permits for international road haulage – the main obstacle for sector development

Serbian hauliers access international road transport market on the basis of bilateral agreements (in most cases under the quota system of bilateral permits) and on the basis of ECMT multilateral quota system of permits. Practically the existence of quotas means limited access to markets, and in some cases exclusion. As a consequence, transport operations are more difficult to organize, efficiency is reduced (primarily through increased number of empty runs), and hauliers have additional costs. Sometimes this is the reason for improper use of permits. This results in a reduced competitiveness of national hauliers, increased environmental pollution and affects foreign trade. The outcome of the study performed in 2007, where major problems in the sector have been defined and the critical ones underlined, shows that insufficient quotas exchanged between Serbia and some other countries and the allocation of permits to hauliers are highly ranked issues (*Medar & Manojlović*, 2011).
When we discuss issues related to foreign trade, one of the solutions of this problem is liberalization of bilateral transport operation. Liberalization of transport which is significant in terms of share in total operations performed is agreed just with 12 countries (Table 3). Liberalization of bilateral transport operation as result of negotiations is, besides facilitating foreign trade as primary objective, motivated by objectives as protection of national hauliers or the environment. Thus, only with seven countries Serbia reached agreement for full liberalization of bilateral transport operations while with two countries partial liberalization was agreed. Most of these countries are neighboring countries, with typically significant value of foreign trade. However, there are countries which are not neighbors or even those with whom there is no significant volume of trade, but both sides have interest to facilitate international transport operations. In recent years, liberalization of bilateral transport operations is standpoint of the Republic of Serbia in

almost all negotiations on road freight transport. Despite this attitude, five countries which are among the top 10 in terms of volume of exports and imports have not yet accepted proposals to liberalize bilateral transport operations, namely Russia, Romania, Italy, Ukraine and Germany. Number of permits for Russia and Italy are critical for many years despite continuous insistence for increase. The main reason is very low share of their hauliers in performed transport operations.

Table 3
Agreed liberalisation of some transport operations between Serbia and other coutries

Country	Liberalized transport operations	Date of effect
Bosnia and Hercegovina	bilateral and transit	1.1.2009.
Bulgaria	bilateral and transit	1.6.2015.
Croatia	transit	1.8.2012.
	bilateral	1.1.2014.
Estonia	transit	30.10.2013.
FRY Macedonia	bilateral and transit for all eco vehicles	1.1.2002.
Hungary	bilateral and transit for EURO 5 vehicles	1.1.2012.
Latvia	transit	16.3.2013.
	bilateral	1.1.2016.
Montenegro	bilateral and transit	6.11.2009.
Romania	transit for EURO 2 vehicles	1.12.2007.
Slovakia	bilateral and transit	2.2.2014.
Slovenia	all	15.6.2005.
Switzerland	all	1.1.2008.

Source: Knežević, 2016

Contingent of permits where the total number of permits exchanged is not sufficient to meet the requirements of hauliers are declared critical. Practically, at the beginning of the year the contingent is critical if more than 80% of permits was used during the previous period or, for example, in September remaining number of permits is less than 20%. Sometimes, even with countries where contingents are not critical or additional number of permits can be exchanged on request, the speed of changes in the market is much faster than the speed of authority's reaction and it happens that non-critical permits became critical during the year. The permits for couple of countries are critical for years as for Austria, France, Italy and Russia, and for some of the countries contingent became critical in last years (Table 4).

Table 4
Some of the countries with critical contingents

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Austria	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Belgium	yes	yes	yes	yes	yes	yes						yes	yes
Czech Rep.					yes		yes		yes	yes	yes	yes	yes
France	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Italy			yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Hungary	yes		yes	yes	yes	yes	yes	yes	yes	yes	yes		
Poland					yes						yes	yes	yes
Russia			yes	yes	yes	yes	yes	yes		yes	yes	yes	yes
Spain							yes		yes	yes		yes	
Romania											yes	yes	yes

Source: Authors based on Annual Distribution Plan of Permits

The relationship between the Republic of Serbia and the Russian Federation is a good example of poor coordination of authorities in charge of trade and transport. During 2000 an agreement was signed between the Federal Republic of Yugoslavia and the Russian Federation on trade of goods with a lower tariff rate (1%) with no provisions for adequate transport liberalization. Initially, the list of products that were covered by the trade agreement was not large, commodity exchange has not increased dramatically, and the Russian market wasn't particularly interesting for hauliers from Serbia. Over the years the list of products covered by the agreement has been expanded and trade quantity in tones transported by road has been more than doubled in 2006. The Russian market has become more attractive and the number of exchanged permits insufficient in relation to demand. The quota of 1,000 permits was sufficient and used at the level of about 30% by 2003. In 2004 usage was increased to 70%, while in the years after the usage grew at almost 100%. Exports and imports in tones transported by road in 2015 has grown 10 times as compared with 2001 and number of permits from 1,000 has been enlarged to 7,500. Insufficient number of bilateral permits resulted in usage of

ECMT multilateral permits for bilateral transport operations between Russia and Serbia, and in significant share of hauliers from third countries.

4. Conclusion

Trade liberalization demands more than tariff reduction and the transformation of non-tariff barriers into tariff rates. When tariff rates are reduced and competition is stifled in some other way or policies, procedures and rules are not applied transparently or systematically or some providers are given preferential treatment the effects of trade liberalization may be lacking. The effects may be negative if a country lacks the necessary adequate institutions, laws and policies.

Non-tariff barriers impede the business operations of hauliers in Serbia and diminish the full effects of foreign trade liberalization. Furthermore, given that Serbian accession to the WTO is in progress a large number of non-tariff barriers, quantitative restrictions and certifications are yet to be in-lined and harmonized with WTO standards.

Acknowledgements

This research was supported by the Ministry of Science and Technological Development of the Republic of Serbia through the projects no. 36006, no. 36010, and no. 36022.

References

IMF. 2001. *Global Trade Liberalization and the Developing Countries*. International Monetary Fund. Available from Internet: <https://www.imf.org/external/np/exr/ib/2001/110801.htm#i>.

ITC. Trade Map Database. Available from Internet: <http://www.trademap.org/>.

Knežević, G. 2016. International road freight transport: Analysis of bilateral agreements of the Republic of Serbia. *Master thesis*. University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia. (in Serbian)

MCTI. 2000-2016. Annual Distribution Plan of Permits: Hauliers Singular Plans (in Serbian), Ministry in charge for transport. At present Ministry of Construction, Transport and Infrastructure. Plans for 2014, 2015, and 2016. Available from Internet: <http://www.mgsi.gov.rs/cir/dokumenti-list/89/172>.

Medar, O.; Manojlović A. 2011. International Road Haulage Industry in Serbia: Critical Issues Analysis, *Journal of Applied Engineering Science*, 9(1): 243-252.

OECD. 2011. *The Impact of Trade Liberalisation on Jobs and Growth: Technical Note*. OECD Trade Policy Papers, No. 107, OECD Publishing, Paris. Available from Internet: <http://www.oecd-ilibrary.org/trade/the-impact-of-trade-liberalisation-on-jobs-and-growth_5kgj4jfj1nq2-en>.

SORS. 2004-2015. *Entry, exit and transit of freight road vehicles, by countries of vehicles registration*, Republic of Serbia. Statistical Office of the Republic of Serbia. Statistics of Transport and Communications. Statistical Releases SV31. Available from Internet: <http://webrzs.stat.gov.rs/WebSite/Public/PageView.aspx?pKey=152>.

SORS. 2004-2015. External trade. Statistical Office of the Republic of Serbia. Statistical Database. Available from Internet: <http://webrzs.stat.gov.rs/WebSite/public/ReportView.aspx>.

SESSION 15: TRANSPORT INFRASTRUCTURE AND INTELLIGENT TRANSPORT SYSTEMS

ABOUT THE PROCESS OF DESIGNING RAILWAY INFRASTRUCTURE

Martin Scheidt[1]
[1] *TU Vienna, Institute of Transportation, Research Center of Railway Engineering, Traffic Economics and Ropeways, Vienna, Austria*

Abstract: Nowadays the process of designing railway infrastructure is mostly seen as a sequential process. The sequential approach would appear to be obsolete, since it is lacking a consideration of customer needs. Therefore, it must be widened and parts of processes must be considered as what they are: sub-processes in a bigger picture. Since the sub-processes are dependent on each other they can be depicted as a cycle. This article presents the cycle of designing railway infrastructure. It has its focus on the German speaking area and aims to give an overview to the tasks and the relationships between sub-processes. It concludes seven sub-processes and eight relationships. It starts with the customer needs for transport which have only been considered indirectly and are generally not one of the primary concerns for designing railway infrastructure. After that a political process determines how to correspond with these customer needs. It includes several inputs like funding, general laws for railway, and the geographic constraints. From the complex political process originates a design target, which is translated into an operational concept. These operational concepts differ in Europe with different focuses on the primary target and an example is discussed as a guide for further development. The operational concepts are then further processed with common evaluation tools to create the bases of design for the infrastructure. There are feedback loops from the evaluation tools to reconsider certain constraints from former sub-processes. After the evaluation tools conclude that an infrastructure is feasible, the infrastructure will be constructed. Later, a specific timetable is constructed on the basis of the infrastructure, which will then be used by customers to full-fill their needs.

Keywords: design, railway, infrastructure.

1. Introduction

The design of the railway infrastructure must take into account different requirements of technical, economical or environmental perspectives. In order to offer services on a railway infrastructure, the design of the track topology is essential. From the track topology, the other infrastructure can then be derived. The track topology therefore offers itself as the base for the design of railway infrastructure.
So far, the process of designing track topology was presented sequentially and processed accordingly (see figure 1, compare Walter, 2016, p. 56). At a closer look, however, shows that all the sub-processes (including first and last stage) are interrelated and therefore should not be considered separated from each other. It therefore makes sense to consider the design of track infrastructure and thus a track topology, as a continuous cyclic process. The cycle may extend over several decades. Since the design of the railway infrastructure is a strategic planning, the operational planning is not considered in the following description.

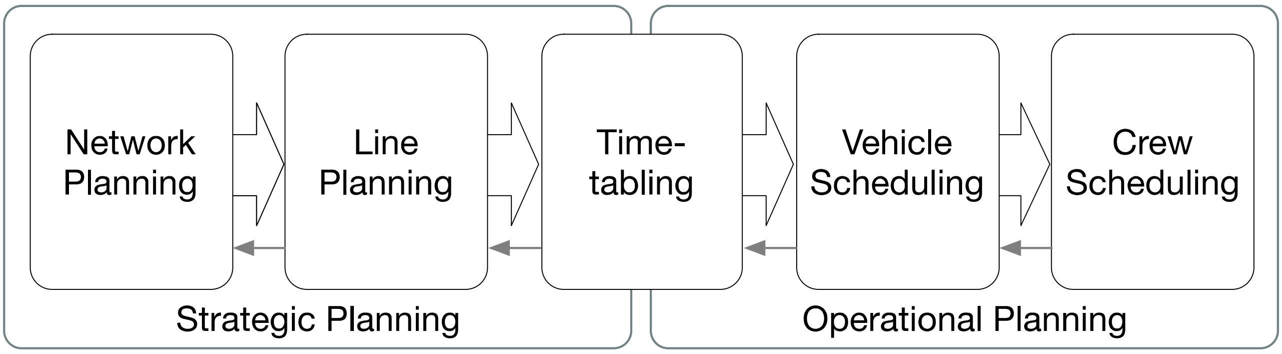


Fig. 1.
Sequential progression of infrastructure planning compare Walter (2016, p. 56)

2. Cycle of Track Topology Design

The individual sub-processes of the cycle can run parallel to each other. Figure 2 illustrates a perception of this cycle. Following paragraphs will discuss the different stages (marked with a circle, i.e. Ⓐ) and their transitions (marked with a diamond, i.e. <0>) in the cycle.

[1] Corresponding author: martin.scheidt@tuwien.ac.at

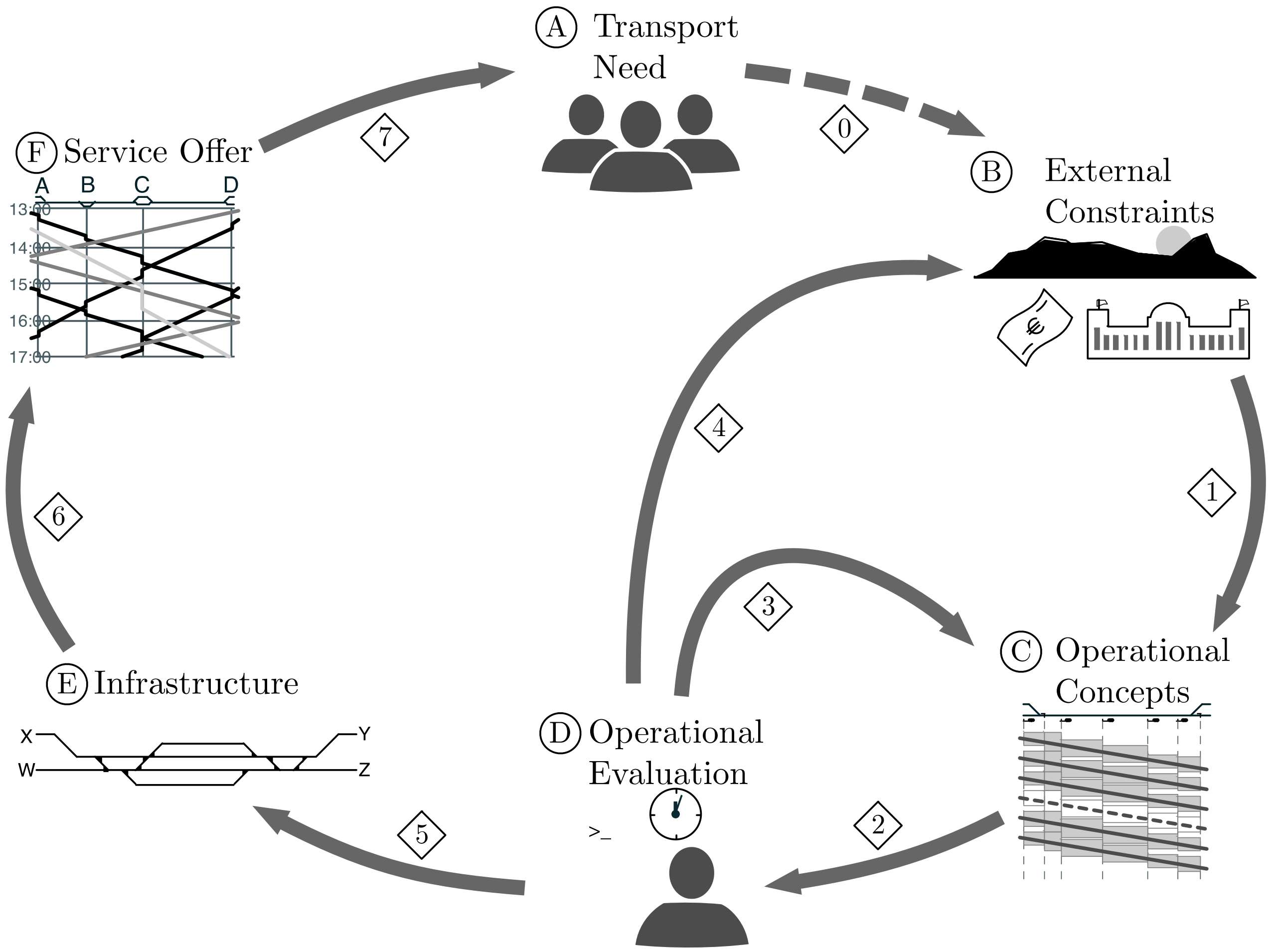


Fig. 2.
Cyclic progression of track topology design

Ⓐ
Means of transport are built for people. People use means of transport to ship goods or travel as a passenger. Use of transport is triggered by the user needs.
The needs come from the spatially relevant basic functions of existence: home, work, care, education and recreation (compare Partzsch, 1970). To satisfy the needs, passenger traffic arises as a mediator between the locations of the individual basic functions of existence. Freight traffic arises from the spatial structure of the economic fabric which provide goods or services to consumers. Needs cannot be satisfied arbitrarily and are in feedback with the transport offer. Therefore, in general, the *transport needs* of users are bundled in corridors and balance against the impact of traffic for the public interest. With this balancing the transport need can be limited in time and space. Spatially through the provision of service and in time by peak, off-peak periods and night's rest.
<0>
A transport demand is derived from the transport need. The derivation is formed by modelling the transport needs in dividing the basic functions of existence in areas which is called a traffic model. There are different models with different gradations to detail and input variables. For instance a traffic model is the Model EVA described in Lohse and Schnabel (1997, p. 250 ff.).
The input parameters and the result of a model need interpretation and training in the handling. Since the interpretation cannot be completely objective, it needs scientific and political work to derive instructions. The instructions from science and politics must not be mutually consistent.
Often the instructions are characterized by the historically developed problem solving strategy in a specific geographic region. Those instructions will be based on the external constraints.
Ⓑ
Under *external constraints* are geography (topology, demography, economic structure, etc.), financing and legal/political directives summarised. All external constraints can be influenced.
The geographical constraints can be influenced by means of engineering works (such as tunnels or bridges), but this is only possible if they are funded. Politics can be influenced by the political will of a region, which in turn affects the legal and financial constraints. Nowadays the political will is mainly influenced by concerns of the financing.
Financing takes place primarily by the public sector in the form of transfer payments. Schwarz (2003) describes how the funding of infrastructure is organised on several levels within a framework of financing arrangements in Germany.

Part of the framework is subsidising transport services as offers on the infrastructure. Offers are created by transport service agencies and are awarded through tendering processes.

Non-financial policy guidelines are implemented through regulation, legislation and related institutions. Riesen (2007) describes how far and how successful regulation are carried out to implement social and economic policy objectives. Motherby (2009) shows how extensive legal regulations can be. All government activities are accountable to laws that are drafted and shaped by the legislative. Institutions such as the German “Bundesnetzagentur” subsequently enforce politically motivated regulation of the transport market within their means.

<1>

From this complex political process specifications arise that are brought to the infrastructure managers. However, at least in Germany, the state infrastructure policy has a major contradiction between restructuring of the state-owned company (i.e. DB AG) and handling a federal-state conflict in infrastructure financing (compare Riesen, 2007, p. 134 ff.). This conflict leads to partly inconsistent or contradictory specifications.

A sensible way to address this is the possibility to define a *service intention* for lines and networks (compare Mahadevan, 2007). Service intention describes holding pattern, operating intervals and times for network sections. E.g. an integral periodic timetable can be adapted by additional trains for higher traffic demand during peak hours. The infrastructure can then be put into dimension based upon such a service intention. In most cases the specifications are not as detailed as a service intention. Usually the specifications are based on desired development stages, which are subsequently determined as a target network.

Ⓒ

The specifications may vary depending on the railway line and location in the network. Often the requirements for capability and behaviour for a railway line are in accordance with the UIC Code 406 (see UIC, 2004). Nevertheless, the sole consideration of capability and behaviour is neglecting the aspects of user-oriented services. Therefore, requirements of service and *operational concepts* are combined.

Operational concepts may vary according to speed, stopping patterns, type of train as well as by primary and secondary networks (compare Weigand and Heppe, 2013, p. 444 ff.). A possible operational concept for a railway line could consist of a superimposed periodic traffic with different holding patterns for passengers and additional freight trains for example. In contrast to a service intention an operational concept is more detailed concerning the data for vehicles and infrastructure.

The larger the area considered, the more complex the operational concept. This way the complexity of a concept of operations for a single region is different than for an entire country. To reduce the amount of data to what is necessary, the area and the level of detail is adjusted. In Radtke (2014, p. 56 ff.) distinction is made in three levels of detail:

- Macroscopic,
- Mesoscopic,
- Microscopic.

By the combination of the considered area, operational concept and level of detail, the inputs are formed (<2>). These inputs are used in the form of a timetable and a desired infrastructure in a railway operation research analysis.

Ⓓ

Operational evaluations are performed to make predictions on the feasibility of a specific concept. For that various tools are available (see Pachl, 2002, p. 137 ff.).

To utilize these tools in a reasonable way, an educated guess is required. The educated guess is an assumption based on knowledge and experience and therefore likely to be correct. However, it results in a lack of transparency of the process and the results. The complex and extensive data storage and many variable factors of each tool make it mandatory that an user contributes experience and knowledge in the handling. Furthermore, the tools have a little intuitive user interface (UI) and use UI concepts from the late nineties.

When performing an operational evaluation with the tools, the creative process of planning is often in the background, data management and data purity are usually more essential. Only a good data pool makes the operational evaluation feasible. In addition, a complex operational evaluation requires high personnel and time effort (compare Martin and Schmidt, 2010). To make the operational evaluation more comprehensible, it requires simple and understandable ways to explain all decisions and document them. Due to the number of variables alone that possibility is severely limited. In total, a better transparency of procedures and results would be desirable.

The result of the operational evaluation is a prediction/estimate about the performance of a concept. If the evaluation meets the original specifications of Ⓑ, the basis for the track topology (<5>) is created. If the evaluation does not meet the specifications, either the specifications or the concept must be adapted.

<3>

Changing in the input variables from the operational concept within the specifications of Ⓒ occurs frequently. The cause of the change is the iterative nature of the operational evaluation (compare Weigand and Heppe, 2013, p. 490). The input variables are altered to approximate a target value in the iterations. The target value is based on existing variables. The educated guess is most commonly used so that the alteration is as close as possible to the goal.

The change is generally a slight modification of the timetable. Otherwise, it may be conducted by infrastructure-side changes (e.g. signal or switch locations or altered track numbers and connections).

<4>
It could be that it is not possible to change the input variables of the operational concept within the specifications. Then the project must either be discontinued or the specifications are to be adapted to make it possible. The adaption then has to be done within the margins of external constraints Ⓑ. One obvious way is to change the mode of financing. Nevertheless, there is also an option to examine the legal framework of operation and therein make other arrangements effective (e.g. BOStrab[2] instead of EBO[3]).
Some operation research analyses are used to evaluate feasibility and recommendations as to the public sector. An example is the feasibility study about the "Deutschlandtakt" (see BMVI - Bundesrepubik Deutschland, 2015).
Ⓔ
When the operational research analysis is completed, specifications (<5>) are formed and the *infrastructure* is constructed by building, adapting or overhauling. The new construction or the adaptation of infrastructure is carried out by a project promoter and the construction firm. However, the ideal condition of the infrastructure after the implementation is only of limited duration. Over its lifetime, the railway infrastructure comes to wear and measures might be taking to ensure traffic safety. This is also a possibility for change in traffic demand. Therefore, a continuous adjustment of the offer (<6>) is necessary.
Ⓕ
In preparation of the *service offer* methods of timetable construction are used (compare Pachl, 2002, p. 175 ff.). The input variables are obtained from the infrastructure, for that an institution (i.e. transport association) or a transport company is able to create an offer. Different timetables are generated depending on the traffic volume in the operational concept Ⓒ. Some timetables are created beyond the scope of the operating concept. Those are e.g. seasonal timetables with additional offers or timetables in phases of maintenance or renewal work.
Due to the timetables a range of transportation links are fabricated. Those links are utilized by users to satisfy their needs of transport (<7>).

3. Conclusion and Critique

The sequential consideration of the design of railway infrastructure appears outdated. It is therefore necessary to extend and represent the dependencies of the sub-processes in a cycle. The transport needs of the user is considered only indirectly and is not commonly in the foreground. The specifications for the design come from complex political processes, which are transferred into service and operational concepts. These concepts are reviewed and assessed to turn them into a basis for the infrastructure and consequently into a timetable.
The cyclic progression of track topology design shows how its individual sub-processes interact. The consideration of the cycle, facilitates the structuring of methods for targeted design of track topology. Since the means of transport are generally established for users, the question arises whether the process should be oriented closer to the traffic demand Ⓐ of the users.
Users can generally only react to the timetable Ⓕ. Without knowing the transport needs, one can make any assumptions for the timetable in the operational concept Ⓒ without consequences. Only after the restructuring of F a timetable it may become evident that the users had other transport needs. There is an urgent need for a stronger focus on traffic demand modeling (<0>).
At the same time, there is a lack of discussion about how far to give in to traffic demand. Even if and where a limit on the fulfillment of the transport need exists. The question of how to find the balance between resource use and free development of mobility needs arises.
The discussion is mainly a social one and primarily driven through politics. Riesen (2007) shows, however, that this task is carried out only to a minor extent. Also missing are binding target definitions within the framework of service intentions (<1>).
In order to implement the service intention purposeful, the design process must move into the foreground with the tools of operational evaluation Ⓓ. Currently, these tools are not comprehensible without an educated guess, and are therefore centered on the feasibility. It is important to make the know-how communicable and comprehensible on a larger scale.

References

BMVI - Bundesrepubik Deutschland. 2015. *Machbarkeitsstudie zur Prüfung eines Deutschland-Takts im Schienenverkehr*, Technical report, Bonn, Germany.
Lohse, D.; Schnabel, W. 1997. *Grundlagen der Straßenverkehrstechnik und der Verkehrsplanung Band 2 - Verkehrsplanung. 2. edition*. Verlag für Bauwesen, Berlin, Germany.
Mahadevan, V. 2007. Describing and evaluating train services on the swiss railway network from a new perspective. In *Proceedings of the Swiss Transport Research Conference*.

[2] The "Verordnung über den Bau und Betrieb der Straßenbahnen" ("Ordinance on the Construction and Operation of Street Railways" / light railway regulations), is a German law regulation governing the field of tramway, metro and light rail operations.
[3] The "Eisenbahn-Bau- und Betriebsordnung" ("Ordinance on the Construction and Operation of Railway" / railway regulations), is a German law regulation specifying rules and regulations for railways.

Martin, U.; Schmidt, C. 2010. *Erhöhung der Effektivität und Transparenz bei Leistungsuntersuchungen mit Simulationsverfahren*, ETR Eisenbahntechnische Rundschau, Hamburg, Germany.

Motherby, M. 2009. Kompendium Eisenbahn-Gesetze. Eurailpress, Hamburg, Germany.

Pachl, J. 2002. *Railway operation and control*. Vtd Rail Pub, Washington D.C., U.S.A.

Partzsch, D. 1970. Daseinsgrundfunktionen. In *Handwörterbuch der Raumforschung und Raumordnung, Band A-H*, p. 424–430.

Radtke, A. 2014. Infrastructure modelling. In *Railway Timetabling & Operations: Analysis, Modelling, Optimisation, Simulation*, Evaluation (2nd ed.). p. 47–62. Eurailpress/DVV, Hamburg, Germany.

V. Riesen, O. 2007. *Zur Leistungsfähigkeit des Regulierungsstaates im Bahnsektor*. LIT Verlag, Münster Berlin, Germany.

Schwarz, A. 2003. Was uns lieb und teuer ist. Finanzierung der Eisenbahn, *Internationales Verkehrswesen*, 55(12): 633-636.

UIC. 2004. CODE 406: Capacity.

Walter, S. 2016. *Long-Term Railway Infrastructure Development*, Thesis, TU Graz, Graz, Austria.

Weigand, W.; Heppe, A. 2013. Spurplangestaltung und betriebliche Infrastrukturplanung. In *Handbuch Eisenbahninfrastruktur*. p. 441-494 Springer Berlin Heidelberg, Berlin, Germany.

ACTIVE AND DYNAMIC RELIABILITY MEASURES BASED ON AUTONOMIC BEHAVIOUR OF ITS

Florin Codrut Nemtanu[1], Marius Minea[2], Ilona Madalina Costea[3], Ciprian Angel Cormos[4], Valentin Iordache[5]

[1,2,3,4,5] *Telematics and Electronics for Transport Dept., Transport Faculty, Politehnica University of Bucharest, Bucharest, Romania*

Abstract: The intelligent transport systems are applications of electronics, communications, sensors and IT in transport and this is the main cause for its high complexity. The complexity has advantages as the increased number of functions provided but has also disadvantages as the decreased reliability is. During the design phase of Intelligent Transport Systems is important to understand this complexity and the effect on the reliability of the system and to implement methods and measures to increase the reliability. The authors proposed in this paper an architecture of ITS based on autonomic behaviour (self-healing, self-optimising and generally speaking, self-* properties) as well as an algorithm to implement active measures to increase the reliability of the system. The algorithm is based on a reliability function defined in terms of ensuring the active reliability in dynamic and complex systems.

Keywords: autonomic ITS, active reliability, ITS reliability, reliability of complex system, reliability measures.

1. Introduction

The Intelligent Transport Systems are now more complex and diverse than the transport processes and they need a special attention in terms of insurance of safety. Safety in transport systems is very important because in these systems the probability of incident appearance is high, compared with other social activities, and the impact is measured in lives and huge amount of money. The role of ITS in increasing the safety is very important (Regan, Oxley, Godley, & Tingvall, 2001) and the new approach is to integrate ITS in transport system as a natural component. For this reason, is important to analyse the impact of ITS, as a component of transport systems, on the safety of transport system. The main condition of insurance a good level of transport safety is that the intelligent transport system has to be able to do its functions, with other words the ITS has to be reliable. A reliable system is a system which is able to be trusted and ITS needs this approach in terms of its intervention in traffic and other safety related aspects of transport.

The reliability of ITS has to be approached at the beginning, during the design of the intelligent transport systems and a reliability model is mandatory to be created and used as a reference for all components of ITS (Kabashkin, 2007).

The reliability of surface transport network is analysed in (ITF, 2010) and the approach could be extended to this research in terms of defining indicators to measure the reliability as well as the most important reliability variables which are included in active measures.

Another important and vibrant approach is the autonomic system. This concept was defined by IBM in (Jacob, Lanyon-Hogg, Nadgir, & Yassin, 2004) and was extended to other domains as transport systems and ITS are (McCluskey, et al., 2016) (Schlingensiepen, Nemtanu, Mehmood, & McCluskey, 2016). The autonomic systems could be designed and implemented in the field of transport systems and the approach of autonomic behaviour could be also used in the development of new ITS for various reasons (in this paper the main motivation is to find a solution to increase the reliability of ITS based on implementation of autonomic functionalities and active measures). The autonomic framework is important at the design stage to integrate these functionalities into the architecture of the system (Schlingesiepen, Mehmood, Nemtanu, & Niculescu, 2013). The challenge in terms of reliability is determined by the new technologies, in ITS the impact of cloud computing will transfer the reliability to other entity and the process will be adapted and the command will be replaced with a request for service.

The reliability of an ITS service is determined by the all components hardware and software and the algorithm implemented could be fundamental for reliability of the system as well the service (Kaparias, Bell, & Belzner, 2008).

The reliability of one component will affect the reliability of intelligent transport system and the reliability of ITS will affect the reliability of transport system as well as the safety of transport system (Oskarbski & Jamroz, 2015) and the main scope is to increase the safety through the reliability of the system. The quality of service (QoS) is another important concept which are able to define the service as well as the system and the reliability of the system is one variable of the QoS (Mocofan, Ghita, Tomas Lopez, & Nemtanu, 2016).

The main idea of this research is to analyse the reliability of complex system, as intelligent transport systems are, and to find the best solution in rising this reliability having as main objective a high level of safety of transport systems.

The paper is started with the analysis of reliability and the main components of it as well as the definition of the reliability functions which will be decomposed into elements. The main factors of reliability are defined in terms of correlating this factors with the general behaviour of the systems. The factors are defined through the variables/objects which are considered as inputs and the reliability function is considered as main output of the system.

Active and dynamic measures to increase the reliability of the system are based on the collection of data from the system, sometimes the monitoring system is able to collect information about the reliability of the components (Costea, Nemtanu, Dumitrescu, Banu, & Banu, 2014) and the system has to receive the commands to modify the value of the variable/object in terms of increasing the reliability of the system.

[1] Corresponding author: florin.nemtanu@upb.ro

2. Description of methods

The reliability of intelligent transport systems is the ability of the system or systems' components to perform its required functions under stated conditions for a specified time. That means, the system has to be designed and installed based on some principles and measures which are able to provide a stable and accurate level of reliability. At this step a definition of the reliability functions is needed and as well as a decomposition of this function.
The reliability of the system is the result of the reliabilities of every component of the system. A reliability function is defined to define and understand the reliability of the system. The ideal value of the reliability function is 1, that means the system is ideal and the system will be able always to perform the functions.

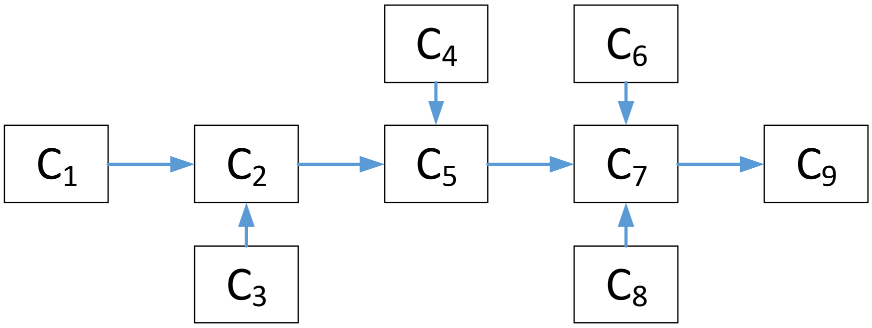


Fig. 1.
ITS structure - global reliability function

In Fig. 1, the system is decomposed into components (C_1 to C_9) and some components are redundant in terms of increasing the reliability function of the system. Every component has a number of variables which are the inputs of the model (the reliability model of the system) and the reliability function is the output of the model.

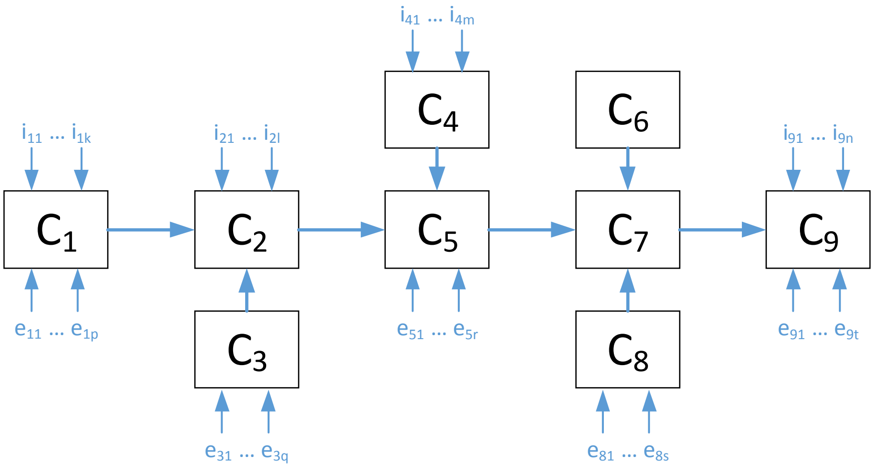


Fig. 2.
ITS components and reliability's variables/objects

Every components of the systems could have two types of input objects or input variables: internal object $\boldsymbol{i_{jk}}$ which is a variable connected to the component itself (design, materials, subcomponents, construction etc.) and an external object $\boldsymbol{e_{fg}}$ which is dependent by the operational environment of the component. These objects are influencing the reliability of the intelligent transport systems and the main objective of this research is to find the best way to increase the reliability of the system through the manipulation of these variables in a dynamic and active manner. All objects $\boldsymbol{i_{jk}}$ of all components are building together a matrix which is the matrix of the internal influenced objects of the system (***I***). All *objects* which have the same characteristics are included in a *class*. The matrix is defined by components (rows) and classes (columns).
The matrix ***I*** is defined as:

$$I = \begin{pmatrix} i_{11} & i_{12} & \dots\ i_{1k} \\ \vdots & \vdots & \vdots \\ i_{j1} & i_{j2} & \dots\ i_{jk} \end{pmatrix} \tag{1}$$

, every row contains the internal objects of reliability for one component of the system and the assumption is that the system has j components; every column contains k classes of internal and external variables of reliability.
And the matrix ***E*** is defined as:

$$E = \begin{pmatrix} e_{11} & e_{12} & \dots\ e_{1k} \\ \vdots & \vdots & \vdots \\ e_{j1} & e_{j2} & \dots\ e_{jk} \end{pmatrix} \tag{2}$$

The reliability of the system will be characterised by the matrix which is the sum of ***I*** and ***E*** (the main assumption is to have the same dimensions of the matrix, *j* and *k*).

The matrix R, reliability matrix, is defined as the sum between ***I*** and ***E*** and has the following expression:

$$R = \begin{pmatrix} i_{11} & i_{12} & \dots\ i_{1k} \\ \vdots & \vdots & \vdots \\ i_{j1} & i_{j2} & \dots\ i_{jk} \end{pmatrix} + \begin{pmatrix} e_{11} & e_{12} & \dots\ e_{1k} \\ \vdots & \vdots & \vdots \\ e_{j1} & e_{j2} & \dots\ e_{jk} \end{pmatrix} = \begin{pmatrix} i_{11}+e_{11} & i_{12}+e_{12} & \dots\ i_{1k}+e_{1k} \\ \vdots & \vdots & \vdots \\ i_{j1}+e_{j1} & i_{j2}+e_{j2} & \dots\ i_{jk}+e_{jk} \end{pmatrix} \tag{3}$$

The matrix R, in expression (3), has *j* rows (one for every component of the system) and *k* columns (one for every classes of objects) and the element *jk* ($i_{jk} + e_{jk}$) is the variable which is specific for the component *j* and the category *k*. The main reason of defining objects as main inputs is to convert, after the elaboration of the methodology, these inputs into software elements which will be able to increase the reliability of the component, at micro level, and the reliability of the system, at macro level.
The matrix R is the reliability matrix of the system and it is a picture of all internal and external variables (objects) and the elements i and e are calculated by the system using data from the design of the components as well as real time data collected from the component. The system will calculate a real time R matrix and will keep the matrix updated (the failure of one component will be registered by the system as well as the cause of the failure – object/class). The process of building and updating the matrix is described in the following figure, using UML diagrams.

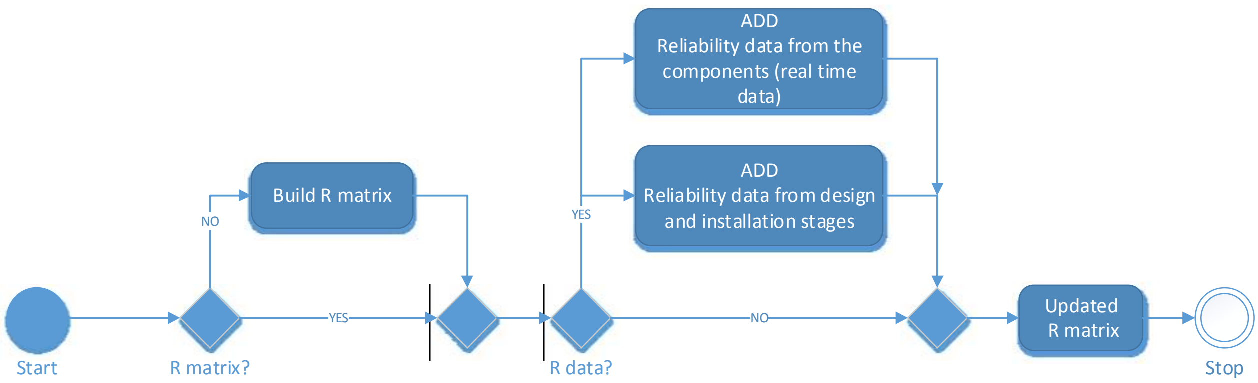


Fig. 3.
The process of building updated R matrix of the system – activity diagram

The process will start with building the matrix R and after that the data will be add to this matrix having as main result an updated R matrix. This R matrix will be used as main input for the active and dynamic measures to increase the reliability of the system. The real time data from various components of the system will be collected form a network of sensors and data loggers which are able to send real time information about the state of functionality for every component.
The paper is focused on the collection of real time data with relevance for reliability of the system and the process which is able to use this data for applying some active and dynamic measures.

3. Works

The solution proposed is based on the collection of real time data about the reliability of every component of the system, the update of the R matrix, the comparison with an ideal R matrix (or target R matrix), the applied measures to increase value of the objects in R matrix. All steps of this process will be done based on the autonomic approach (without any human intervention and based on machine learning techniques).
The model for testing the method is created in LabVIEW and 4 components of the system will be considered as well as 4 classes. The 4 components of the system, selected for this case are: the server, the display wall, bundle of cables and the HMI consoles. The 4 classes selected for this experiment are: temperature (t), humidity (h), vibration (v) and mechanical stress (m).

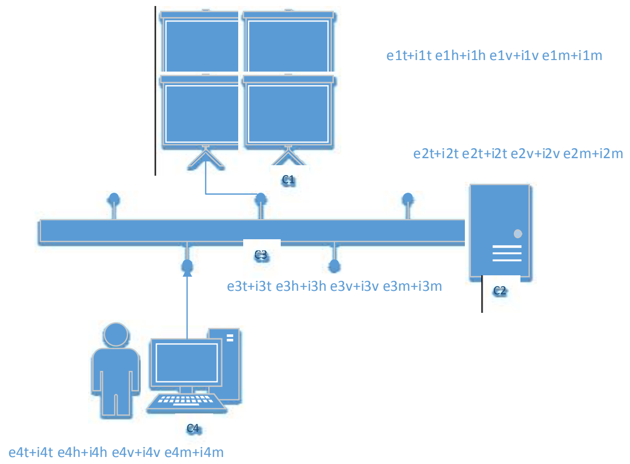


Fig. 4.
The model of the system

Based on the Fig.2 the model of the system (Traffic Management Centre) is presented in Fig.4 and the internal and external reliability objects are presented for all 4 components of the system. The R matrix of the system showed in Fig. 4 has the following expression:

$$R = \begin{pmatrix} e_{1t}+i_{1t} & e_{1h}+i_{1h} & e_{1v}+i_{1v} & e_{1m}+i_{1m} \\ e_{2t}+i_{2t} & e_{2h}+i_{2h} & e_{2v}+i_{2v} & e_{2m}+i_{2m} \\ e_{3t}+i_{3t} & e_{3h}+i_{3h} & e_{3v}+i_{3v} & e_{3m}+i_{3m} \\ e_{4t}+i_{4t} & e_{4h}+i_{4h} & e_{4v}+i_{4v} & e_{4m}+i_{4m} \end{pmatrix} \tag{4}$$

The implementation of the measures is done based on the following algorithm in terms of maintain or increase the reliability of the intelligent transport system. The algorithm is defined to increase the reliability based on collected and initial data.

4. Results

The active and dynamic reliability measures based on autonomic behaviour is realised based on a LabVIEW programme which is able to collect information from sensors (based on the data acquisition boards) and from data logger (based on importing function). In the example, the authors are implementing both sources of data for initial form of R matrix: sensors and data loggers.
The process of implementing the active and dynamic measures to increase the reliability of ITS is described in the following diagram:

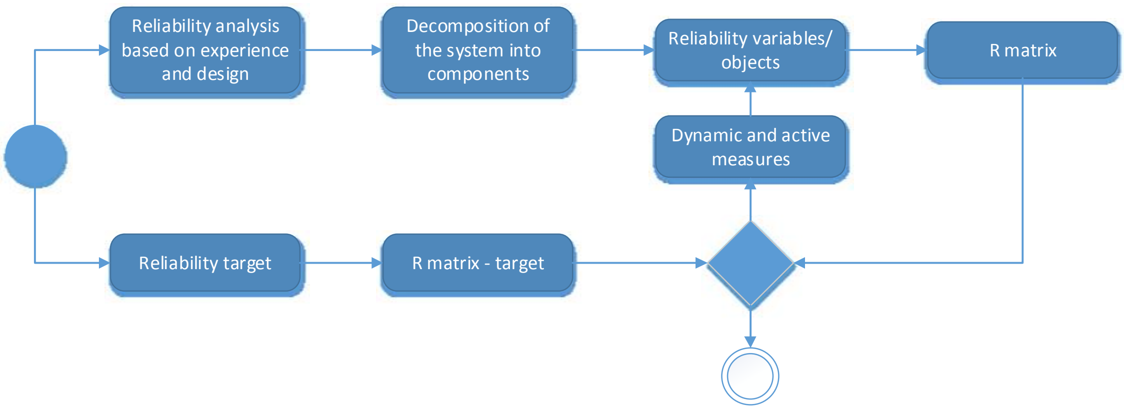


Fig. 5.
The process of increasing the reliability using R matrix

The implementation in LabVIEW has both exchange of data from data logger and sensors to the system. Based on collected data, the virtual instrument (vi file) will update the R matrix, it will compare the R matrix with the target matrix and it will send the variables to actuators to increase the reliability of the system.

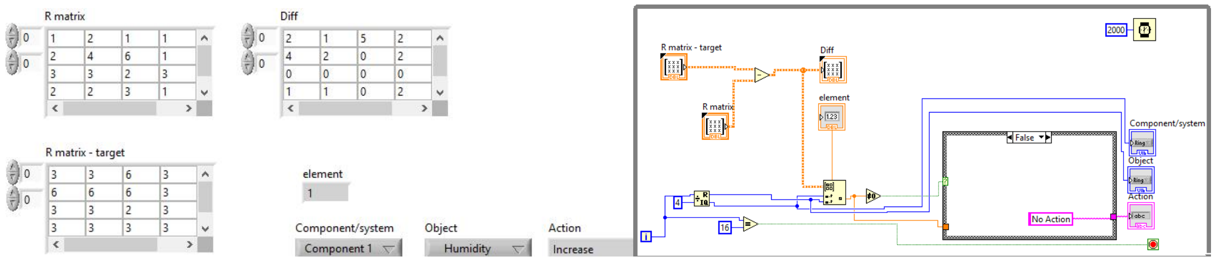


Fig. 6.
The Front Panel and Block Diagram of main VI

In Fig. 6 the R matrix is generated locally and the next step is to generated R matrix based on sensors and log files. In the same virtual instrument, the difference between R matrix and R matrix target (which is the matrix objective) is calculated and the result is displayed in Diff matrix. If the element (the number of the component as row and the object/variable as column) of Diff matrix is 0 the programme will do nothing, else, the programme will try to increase the value of the object and will send a command to an actuator or command element (for instance the command of AC to decrease the temperature).

5. Conclusions and recommendations

The main scope of this paper is to analyse the reliability of the intelligent transport systems and to find the best measures to increase the level of reliability through active and dynamic ways.
The analyse of the reliability is done through a matrix which is the main tool and will be the container of initial information as well as the real time data collected form the components of the system. The matrix will be integrated in the process of increasing the reliability of ITS. The main issue of the matrix is to populate it with internal and external objects/variable (i_{jk} and e_{jk}) and the definition of these objects.
The matrix as a tool was choose to pave the way for future mathematical processing and to facilitate the implementation of the algorithm in various software environment.
The implementation of the method in LabVIEW has the following advantages:

- The collection of data from various sensors based on the DAQ boards which are native integrated in LabVIEW,
- Import and export of files, in different format, is very facile,
- The possibility of implementation of mathematical calculus (Matlab integration facilitate),
- The existence of GUI objects,
- The possibility of actuating hardware components.

The autonomic behaviour is based on Artificial Intelligence, machine learning and other computer science technologies and it has as main result the increasing of reliability (and the efficiency of the measures of the system's reliability).
The increasing of the reliability is fundamental, not only for intelligent transport system, but also for transport system in terms of increasing the efficiency of ITS implementation. Sometimes the reliability of the ITS is strong connected with the functionality of transport system where the ITS are installed.
During the research activity the authors elaborated the following recommendations, based on the objective of this paper:

- The stability of the system after the implementation of the solution to increase the reliability of the system;
- The initial values of the R matrix are fundamental in the first stage of the implementation of the solution and the effect is decreasing at the next stages,
- The software environment is used as an integration platform and has to be able to collect data from components and to be ready for the implementation of the algorithm,
- The internal and external objects have to be defined based on the experience and best practice and have to be calibrated based on the real time data collected form sensors and data loggers,
- For components implemented in a cloud environment the command to increase the value of the object in terms of reliability will be replaced with a request for service (the system will send a request to cloud service provider to increase the reliability of the component).

References

Costea, I.M.; Nemtanu, F.C.; Dumitrescu, C.; Banu, C.V.; Banu, G. S. 2014. Monitoring system with applications in road transport. In *Proceedings of the IEEE 20th International Symposium for Design and Technology in Electronic Packaging (SIITME)*, 145-148.
ITF 2010. *Improving Reliability on Surface Transport Networks*, OECD Publishing, Paris, France.
Jacob, B.; Lanyon-Hogg, R.; Nadgir, D.K.; Yassin, A.F. 2004. *A Practical Guide to the IBM Autonomic Computing*, IBM Red Books, U.S.A.

Kabashkin, I. 2007. Reliability Model of Intelligent Transport Systems. In *Proceedings of the 7th International conference on Intelligent Transport Systems Telecommunications*.

Kaparias, I.; Bell, M.G.; Belzner, H. 2008. A New Measure of Travel Time Reliability for In-Vehicle Navigation Systems, *Journal of Intelligent Transportation Systems*, 12(4): 202-211.

McCluskey, T.L.; Kotsialos, A.; Müller, J.P.; Klügl, F.; Rana, O.; Schumann, R. 2016. *Autonomic Road Transport Support Systems*, Birkhäuser Basel, Basel, Schwitzerland.

Mocofan, A.M.; Ghita, R.; Tomas Lopez, V.R.; Nemtanu, F.C. 2016. Quality of services solution for efficient communication within a distributed urban traffic control system, *Scientific Bulletin of Politehnica University Bucharest*, 175-186.

Oskarbski, J.; Jamroz, K. 2015. Reliability and safety as an objective of Intelligent Transport Systems in urban areas. *Journal of Konbin*, 2(34): 59-70.

Regan, M. A.; Oxley, J. A.; Godley, S. T.; Tingvall, C. 2001. *Intelligent transport systems: safety and human factors issues*, Royal Automobile Club of Victoria (RACV), Melbourne Vic Australia, Australia.

Schlingensiepen, J.; Nemtanu, F.C.; Mehmood, R.; McCluskey, T.L. 2016. Autonomic Transport Management Systems—Enabler for Smart Cities, Personalized Medicine, Participation and Industry Grid/Industry 4.0. In A. Sładkowski, & W. Pamuła, *Intelligent Transportation Systems – Problems and Perspectives* (pp. 3-35). Springer International, Germany.

Schlingesiepen, J.; Mehmood, R.; Nemtanu, F.C.; Niculescu, M. 2013. Increasing Sustainability of Road Transport in European Cities and Metropolitan Areas by Facilitating Autonomic Road Transport Systems (ARTS). In *Proceedings of theThe International Conference on Sustainable Automotive Technologies*, 201-210

ROAD SAFETY IN TUNNELS: THE ECOROADS PROJECT

Marios Miltiadou[1], Liljana Cela[2], Mate Gjorgjievski[3]
[1,2,3] *South East Europe Transport Observatory (SEETO), Serbia*

Abstract: Safety in tunnels is usually focused on risk management in case of incidents more general than road accidents (fire, collisions or car breakdown, etc.) and the safety measures and response to these incidents according to the 2004/54/EC Directive. The Road Infrastructure Safety Management Directive (2008/96/EC), which does not apply in tunnels, could be beneficial for risk prevention in tunnels, focusing on infrastructural elements seen from the road safety point of view. The "Effective and Coordinated Road Infrastructure Safety Operations" (**ECOROADS**) is an on-going project, which is financed by the EU Horizon 2020 Programme. Its general objective is to overcome the barrier emerging from the formal interpretation of the Road Safety and Tunnels Safety Directives that do not allow Road Safety Audits and Inspections (**RSA/RSI**) to be performed in uniform way along both open roads and tunnels. In this aspect, the project experiments on an integrated approach for road infrastructure and tunnel safety management, on the basis of the existing legislative framework, the available experience of road and tunnel experts and best practices. This common approach is tested at five sites in Central and Southeast Europe, where joint safety operations are performed by a mixed team of (tunnel and road) experts. This paper presents the ECOROADS approach, the results of the field tests that have been performed by August 2016 and the evaluation of the experience gained towards the improvement of this approach and the formulation of recommendations for incorporating road safety operations into tunnel safety procedures.

Keywords: road safety, tunnel safety, South East Europe, ECOROADS project.

1. Introduction – The ECOROADS project

RSA during project design or RSI after opening to traffic, according to the prescriptions of the Road Infrastructure Safety Management (**RISM**) Directive 2008/96/EC (European Commission, 2008), could be beneficial for risk prevention in tunnels. However, the RISM Directive does not apply in road tunnels, which are covered by the Tunnels Directive 2004/54/EC (European Commission, 2004) that mainly focuses on safety issues and risk management in case of hazardous incidents. The strict application of the two Directives leads to a non-uniform approach to the infrastructure safety management outside and inside tunnels and the ECOROADS objective is to experiment on merging the road and tunnels safety procedures in one integrated approach for joint road safety operations.
The project comprises workshops with stakeholders (European tunnel and road managers), exchange of best practices and experiences between tunnel experts and road safety professionals, joint pilot safety operations (field tests) at five European road sections that feature both open roads and tunnels, and - based on the results of these field tests – the formulation of recommendations for the application of the RSA/RSI concept in tunnels.
Based on the outcomes of the 1st project Workshop with stakeholders and a seminar for exchange of best practices between road and tunnel experts (September and November 2015, respectively), the relevant Directives, the available literature and the results of national and international research projects, the Common Procedures for the field tests were elaborated (ECOROADS Consortium, 2016a).
Then, from the experience gained from the first two field tests, the experts' feedback and the evaluation made during the 2nd project Workshop with stakeholders held in June 2016, the common procedures are fine-tuned during the second set of field tests organized within the period August – October 2016, paving the way for the formulation of the project recommendations for joint road and tunnel safety operations.

2. Common procedures for joint road safety operations in roads and tunnels

The ECOROADS Common Procedures concern the organization, performance, reporting and evaluation process, including the roles and responsibilities of visiting teams, the tools and methods to be used, the road/ tunnel safety elements to be assessed, etc. (Miltiadou M. et al, 2016).

2.1. The ECOROADS test sites

The ECOROADS test sites have been selected among several candidatures, following a multi-criteria ranking procedure, taking into account different parameters related to the infrastructure and the project particularities, i.e. the relevance to the project, the readiness of the hosting Road Authority/ Infrastructure Managers (**IMs**) and completeness of the candidature (information and data), and budgetary issues (accessibility to site, mobilization of experts, etc.).
All sites are located along sections of the Trans-European Transport Network (**TEN-T**) and its extension in the Western Balkans and are presented below, according to the project scheduling:

- **1st set of field tests:**
  - **Kennedytunnel, Antwerp - Belgium:** RSI at a 690m long tunnel under Schelde River, which consists of two unidirectional tubes with three lanes each for car traffic (also 1 tube for train traffic and 1 for pedestrians and cyclists). *Procedure concluded (March – May 2016)*

[1] Corresponding author: mmiltiadou@seetoint.org

- **Krrabe tunnel, Tirana – Elbasan highway - Albania:** RSI at a twin tube tunnel (2.23-2.5km) with two lanes each. Open road section on the one side of the tunnel is a motorway (RSI), while motorway construction works are unfinished on the other side (RSA). *Procedure concluded (April – May 2016)*

- **2nd set of field tests:**
  - **BAB A71/ Rennsteig Tunnel - Germany:** 19.6km motorway (two traffic lanes per direction) with four consecutive tunnels with total length of 12.6km included. Proposed site for RSI: 10.3km (including the longest tunnel, 7.9km). *Procedure commenced – Site visit performed in August 2016*
  - **Belgrade bypass Strazevica tunnel, Serbia:** RSI at single tube tunnel (745m long) with one lane per direction (bidirectional traffic), along the Belgrade bypass, which is foreseen to be constructed in full motorway profile. *Procedure commenced – Site visit scheduled for September 2016*
  - **Demir Kapija tunnel, Corridor X – Former Yugoslav Republic of Macedonia:** RSI at a single tube tunnel (554m long) with one lane per direction. Open road section on the one side of the tunnel is a motorway (RSI), while construction works are unfinished on the other (RSA). *Procedure commenced – Site visit scheduled for October 2016*

The joint operations at all sites should be performed bi-directionally on adjacent (to the tunnel) open roads, transition areas and tunnel interior, presented in **Figure 1**.

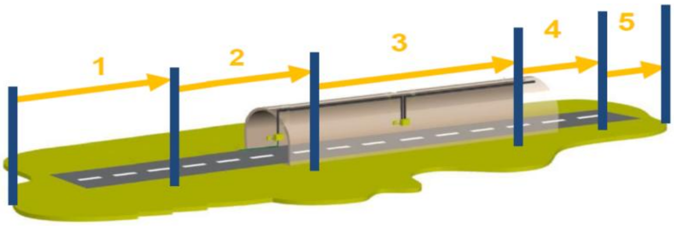


Fig. 1.
Segmentation of infrastructure for the ECOROADS field tests
Source: ECOROADS Consortium, 2016a

The length of the open road in each field test is defined, taking into account the influence of the tunnel before the transition area of the tunnel and it is defined based on the local conditions and particularities, after receiving information from the IMs and local experts, and taking into account the distance of warning of road users about the existence/ approach to the tunnel (vertical signage and road marking) and the presence of adjacent interchanges, entry/ exit ramps, weaving maneuvers, etc.
The transition area between an open road and a tunnel for the scope of ECOROADS project, is defined at least as the sum of a) the distance calculated as the distance covered in 10 seconds by a vehicle travelling at the speed limit before the tunnel portal and b) the stopping distance after the tunnel portal, for a vehicle travelling at speed limit, if not identical with design speed. This minimum rule obviously applies on the opposite direction and also - maybe slightly modified due to reduced speed within the tunnel - at the exit of the tunnel and on the same direction. The stopping distance may be calculated according to the World Road Association (PIARC, 2003), using the initial vehicle speed and other important factors, such as the driver reaction time, the longitudinal friction coefficient or the vehicle deceleration rate. Obviously, the tunnel interior section for this exercise is defined as the remaining part of the infrastructure between the transition areas on both sides of a tunnel (ECOROADS Consortium, 2016a).

2.2. Organization, planning and involved parties

Each RSA/RSI is performed by a Core Team, which is an international team of experts that jointly and independently (from the IMs) perform an RSA/RSI at a designated field test and report on their findings. This team consists of at least three and preferably four (2 road + 2 tunnel) experts, with one of road safety experts as Team Coordinator. The Core Team is part of a wider RSA/RSI Group, composed additionally by a “Facilitator”, representative(s) of the host organization/ IMs, “External” observers, an “Internal” observer, and other external experts and stakeholders.

Specifically, the participants and their roles are:

- **“Facilitator”:** a local/ national expert and member of the ECOROADS consortium that ensures a direct link with the IMs for organizational and operational purposes.
- **Infrastructure (Road/ Tunnel) Managers or State/ Regional Road Authority:** co-organizes and facilitates the RSA/RSI, provides the necessary information and data and responds to the RSA/RSI Report.

- **“External” Observers:** stakeholders with different competences, representing different authorities that can provide information to the Core Team (particularities of a test site, seasonal conditions, peak months, raining or hard winter days, etc.).
- **Other “External Experts” and Stakeholders:** experts/ stakeholders from local and national interested parties (incl. road user groups and associations), which provide complementary information.
- **ECOROADS “Internal” Observer:** a member of the ECOROADS consortium, who participates in a field test, reports to the consortium and ensures the effective monitoring and the proper and homogeneous application of the Common Procedures.

Two meetings of the RSA/RSI Group are organized at each field test:

- a **Briefing Meeting**, for presenting to the participants the scope and procedures of ECOROADS field tests, for presenting details of the project under RSA/RSI to the Core Team, for providing clarifications on issues that emerged from the available data and information, and for gathering information and opinions from external experts and stakeholders; and
- a **Completion Meeting**, for the presentation of their preliminary findings by the Core Team and for the coordination of further activities (reporting, feedbacks, deadlines).

The reporting, feedback and monitoring process comprise:

- the RSA/RSI Report of the Core Team: report with the identified road safety deficiencies, delivered to the IM and the other members of the RSA/RSI Group, with description of the proposed measures and experts’ recommendations/ advice for solutions to alleviate problems and to reduce risks and accidents’ numbers or severity in the short-, medium and long-term.
- the feedbacks from all members of the RSA/RSI Group, on specific templates designed per participant's role.
- a Report of the “Internal” Observer on the conformity of the procedures followed with the Common Procedures.
- feedback from the IM on the RSA/RSI Report.
- the Final Report, taking into account the response of the IM.

The workflow of the aforementioned activities is summarised in **Figure 2** for the first set of the field tests. The same cycle is foreseen - after fine-tuning the procedures - during the second set of the field tests.

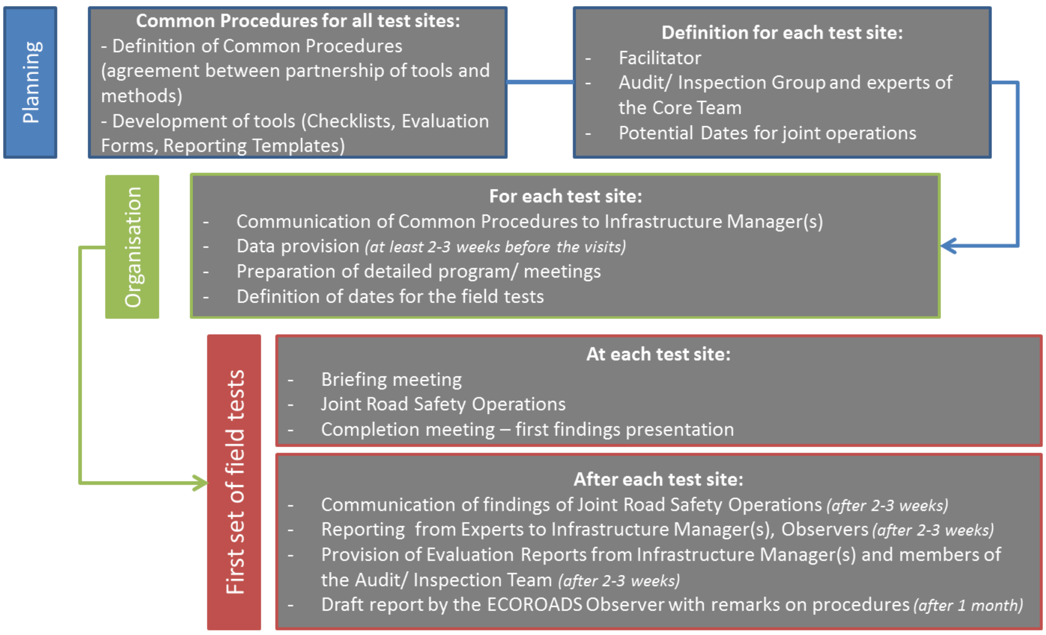


Fig. 2.
ECOROADS organisational and planning process for the field tests
Source: ECOROADS Consortium, 2016a

2.3. Tools and methods

Generally, the tools and methods defined by the ECOROADS Common Procedures (technical equipment, checklists, templates for reporting and evaluation) are in accordance with international and national best practices and recommendations, slightly modified and adjusted to serve the project aims and needs. These comprise, inter alia, the following:

Provision of all necessary data: it is fundamental for the success of the RSA/RSI operations. The required data and documents are explicitly defined for RSI, whilst for RSA vary depending on the project maturity and the RSA level to be carried out, considering that the prepared or on-going (under construction) projects are well advanced in terms of design, as well as that RSA at different road project phases are not always performed by the various countries where the test sites are located.

Exploitation of pictures and video recordings: they should be used for preparation purposes, as well as for the preparation of RSI report. The exploitation of such material is encouraged, considering the limited time on site and for ensuring the least exposure of the RSA/RSI Group to traffic during inspections. Given also the project particularities that require mobilization of people from different European countries, the most advanced equipment and practices usage is encouraged during the field tests, ensuring less time-consuming operations and at the same time less exposure of the RSA/RSI Group to traffic.

Ensuring safety during site visits: especially regarding safety, both for the road users and for the RSA/RSI Group, appropriate measures are taken, in cooperation with the IMs and Traffic Police. The particularity of carrying out inspections on high speed roads and in tunnels requires more radical safety measures, with closures of traffic lanes), which requires appropriate warning signage (road works and directional signs, flashing lights) at specific distance before the closure occurs.

Tunnel inspections are preferably carried out during the closure of tunnel tubes for maintenance. Days and hours of the field tests should be decided according to the project needs, the traffic conditions and the possibilities for infrastructure closure, and thus with a concern to balance project needs with safety requirements. This enhances the need of dedicating more time in preparatory, in-house work and exploitation of any data and material that would be made available before the field tests.

The use of official cars for the transfer to the site and during the inspection would be most preferable, having appropriate warning signage (flashing lights). Members of the RSI Group have to respect the road/ tunnel rules and when outside from the inspection car - where this is permitted - should wear phosphorescent vest and take care not to burden the traffic and road users' behavior with any unpredicted behavior or risky activities on site.

Use of checklists: their use is recommended, as a mean that ensures a homogeneous approach and assessment of road safety and at the same time the avoidance of failures of noticing all safety problems, minimizing the possibility of overlooking some important safety elements due to a more loose approach by the experts, due to their expertise on specific aspects.

For the scope of the ECOROADS exercise, the RSA/RSI checklists proposed by PIARC are adopted as a basis of work specifically for open roads, as also used in the SEETO checklists (COWI, 2014). Especially concerning tunnels and transition areas, two checklists were composed, comprising aspects that influence road safety in these sections (e.g. sharp curves of the alignment near the tunnel, unprotected edges at portals, use of ordinary road markings instead of rumble strips), taking into account:

- the relevant EU Directives' criteria;
- elements for tunnel safety assessment included in checklists in various countries;
- relevant national RSA/RSI guidelines that include such provisions for RSA/RSI in tunnels (ARSF, 2014), (NPRA, 2014);
- the findings and recommendations of the "Human Factors and Road Tunnel Safety Regarding Users" (PIARC, 2008), and
- the RSA training material for safety in tunnels (Nitche P., 2010),

provided that the aspects to be checked in ECOROADS tunnels and transition areas should not be all those of the Tunnel Directive, but the main criterion of their inclusion in checklists should be oriented to road user' safety.

The elements of the checklists drafted for tunnels and transition areas are presented in **Tables 1 and 2**, respectively.

Table 1
Elements of Checklists for tunnel interior

A. Function, operating elements and surrounding/ road environment: 1. Information about previous RSA/RSI or Tunnel Safety Inspection final results. Issues from accident data; 2. Type of tunnel (twin tube, bidirectional, urban); 3. Design (tubes, lanes, special lanes for HGVs) and traffic characteristics (volume, HGVs proportion); 4. Transport of dangerous goods. Drainage for flammable and toxic liquids; 5. Tunnel height. Height control system for HGVs. Overtaking of trucks prohibited; 6. Water supply at appropriate intervals (250m); 7. Ventilation system/ Congestions likelihood and adequacy of ventilation system; 8. Provisions for prevention of spreading of fire and liquids inside and between tubes; 9. Equipment sufficiency (type, location, fire resistance); 10. Means for prevention of smoke and heat from reaching escape routes; 11. Emergency power supply; 12. Special weather conditions (humidity, fog, etc.) causing lack of sight due to vehicles air-conditioning/ ventilation; 13. Clean/ pleasant/ comfortable driving environment; 14. Overtaking or reversing in bidirectional tunnel; 15. Evacuation plans.
B. Cross section: 1. Same number of traffic lanes maintained outside and inside the tunnel; 2. Lanes' width; 3. Existence of emergency lane or paved shoulder (at grade or elevated)/ emergency walkways; 4. Means used along the median for separation of the two directions of traffic in bidirectional tunnels; 5. Cross-connections for emergency services for twin tubes longer than 1500m, ensuring safety of turning movements, considering the traffic density.
C. Alignment, horizontal & vertical: 1. Longitudinal gradient > 3 and ≤ 5%; 2. Cross falls; 3. Curvature (big radii).
D. Intersections/ Interchanges: 1. Junctions inside the tunnel. Adequacy of geometrical characteristics of intersection/ interchange and of entry/ exit lanes. Existence of dangerous weavings; 2. Adequacy of directional signing; 3. Sight distance; 4. Drainage system.
E. Laybys/ Emergency stations/ Emergency exits: 1. Lay-bys provided (especially when no emergency lanes exist). Adequacy of location/ density (1km intervals). Visibility. Design and dimensioning appropriate (length, width, transition sections). Distances to the portals and/or emergency exits indicated. Inclusion of emergency station; 2. Emergency stations sited at appropriate intervals (every 150m) and adequately equipped (telephone, extinguishers). Equipment available operational and offered for use by different type of users, incl. vulnerable ones (e.g. height for access); 3. Passive safety devices (barriers, impact absorbers); 4. Emergency exits for the users. Adequate number/ density (500m intervals); 5. Information provided to users and guidance/ channelization to reach emergency exits/ escape routes; 6. Appropriateness of emergency exits' type (direct to outside/ connection to other tube/ exit to emergency gallery/ shelter with escape route separate from tunnel tube) for different types of users, incl. vulnerable ones (walking length, existence of stairs, gradients, etc.); 7. Existence of emergency driver information systems (sirens, flashing lights) indicating emergency exits.
F. Traffic signals/ ITS: 1. Traffic lights or message signs; 2. Existence/ location/ intervals of signals (in long tunnels every 1km) indicating that no special conditions emerged and that the tunnel is continuously monitored; 3. Existence of VMS systems. Categories of information (congestion/ breakdown/ accident/ fire/ open-close-divert/ speed limit/ lanes allocation to vehicle categories). Understandable messages. Appropriate VMS category for switching engines off in case of congestion. VMS only in text or accompanied by pictograms; 4. Existence of tunnel control centre (for the specific one or centralized for several tunnels); 5. Video monitoring system; 6. Automatic incident detection and/or fire detection; 7. Radio re-broadcasting frequencies for emergency services and users. Radio frequency adequately communicated to the users. Loudspeakers or other communication equipment in shelters and exits.
G. Traffic signing, marking and lighting: 1. Appropriate signs used for Lay-bys, Emergency exits, Escape routes, Emergency stations, Radio, Indication of the remaining length; 2. Signs succinct in form and repeated for clarity; 3. System of signs and signals based on use of graphic symbols and/or narrative labels; 4. Signs and signals perceivable, simple, readable, credible, reliable, memorable and easily to understand (also for non-nationals); 5. Intervals of each signing category appropriate, harmonised with the driving speed; 6. Signs and signals well dimensioned, coloured, lighted and repeated frequently in a proper way; 7. Information system not complicated (e.g. numerous written instructions); 8. Sufficient (regular) chainage information, providing indication where the vehicle's position is inside the tunnel (remaining distance/ distance covered); 9. Warning signs before the last interchange that a tunnel is ahead to avoid stressful driving, over-height vehicles and provide exit of vehicles carrying dangerous loads; 10. Horizontal signing used at the roadside edge; 11. (Reasonable) compulsory driving distance between vehicles and relevant marking and signing (e.g. chevrons); 12. Use of profiled markings. Need for LED lighting; 13.Visibility in the tunnel sufficient (normal, safety, and evacuation lighting assessment); 14. Guidance systems in good condition (e.g. soiling of reflectors or functionality of LED lamps on raised shoulders); 15. Junctions, facing walls, and the like sufficiently shielded.
H. Roadside features and passive safety installations: 1. Restraint systems/ guardrails; 2. Crash cushions and impact attenuators and type; 3. Need for refurbishment to avoid risks for users from degradation of outdated equipment; 4. Emergency phones; 5. Fixed objects that could cause possible collision: Structural elements (vault, angle niche/ cross-connection, etc.), Roadside elements (guardrail, redirection profile, sidewalk, etc.), Non-structural elements (system or equipment support, fan, VMS, etc.); 6. General risks of collision between vehicles.

Table 2
Elements of Checklists for transition areas

A. Function, operating elements and surrounding/ road environment: 1. Information about previous RSA/RSI or other safety assessment (Tunnel Safety Inspection) final results. Issues from accident data; 2. Radio re-broadcasting frequencies. Radio frequency adequately communicated to the users; 3. Information provided to the users about their correct behaviour while driving through a tunnel (use headlights, avoid sunglasses, keep distances, observe signs and signals, switch the radio on and tune to indicated frequency); 4. Information provided to users about the possible incidents in tunnels and appropriate reaction; 5. Special lanes for HGVs or reduced speed limit for trucks. Affection of traffic flow. Overtaking of trucks prohibited; 6. Water supply provided near portals; 7. Gradual reduction of speed from open road to the tunnel speed limit.
B. Portal: 1. Safe design of tunnel portal for all vehicle types (funnel shape and gradual height reduction); 2. Risk of heavy vehicles hitting the tunnel ceiling or walls; 3. Portals sufficiently shielded; 4. Entrance having slowing down effect due to its design (not informative, dangerous, confining).
C. Cross section: 1. Paved area narrowed and lateral clearance reduced at entrance causing speed reduction and driving in more distance to tunnel sidewalls; 2. Same number of traffic lanes maintained outside and inside the tunnel. Sufficiency of different traffic lanes' widths; 3. Crossing of central reserve ensured outside each portal; 4. Appropriate means used along the median for separation of the two directions of traffic in bidirectional tunnels.
D. Alignment, horizontal & vertical: 1. Alignment (straight, not on curve); 2. Cross-fall; 3. Longitudinal gradient > 3 and ≤ 5%.
E. Intersections/ Interchanges: 1. Junctions inside or before-after the tunnel; 2. Adequate directional signing; 3. Dangerous weavings.
F. Traffic signals/ ITS: 1. Located well ahead the portal (150m-200m), where the drivers do not pay attention, as they are focused to the tunnel entrance; 2. Located before the entrances to ensure the closure of the tunnel in case of emergency; 3. Visibility of the traffic signals ahead of the portals in good time; 4. VMS systems. Categories of information (congestion/ breakdown/ accident/ fire/ open-close-divert/ speed limit/ lanes allocation to vehicle categories); 5. Understandable VMS messages. Messages only in text or accompanied by pictograms; 6. Possibility of posting speed limit signs at sufficient intervals to safely reduce driving speeds; 7. Need for Automatic Traffic Control.
G. Traffic signing, marking and lighting: 1. Proper distance between signs, harmonised with the driving speed; 2. Objects/ reasons of distraction of drivers from concentrating on tunnel entrance (irrelevant signs/ advertisements); 3. Signs succinct in form and repeated for clarity; 4. Signs perceivable, simple, readable, credible, reliable, memorable and easily to understand (also for non-nationals); 5. Signs and signals well dimensioned, coloured, lighted and repeated frequently in a proper way; 6. Information system not complicated (e.g. numerous written instructions); 7. Warning signs before the last interchange that a tunnel is ahead to avoid stressful driving, over-height vehicles and provide exit of vehicles carrying dangerous loads; 8. Horizontal signing used at the roadside edge; Road markings – profiled markings used. Need for LED lighting; 9. Rumble strips (acoustic lane markings) located ahead of the portals; 10. Right illumination level chosen at the entrance zone, transition zone. Illumination level satisfies all lanes; 11. Entrance into the tunnel adequately lighted; 12. Adaptation lighting (adjustment of the light intensity level) at the beginning and end of the lighting/tunnel; 13. Sight conditions at entrance poor (ocular blinding, stray light, etc.); 14. Vehicles' headlights usage obligatory and this clearly communicated with appropriate signing; 15. Entrance zone designed to provide as low adaptation luminance as possible.
H. Roadside features and passive safety installations (incl. plantings, civil engineering structures and other obstacles): 1. Restraint systems/ guardrails; 2. Need for guardrail in the portal zone. Guardrail well anchored and extended back both outside and inside the tunnel; 3. Passive objects for minimising the consequences of accident at the portal area. Crash cushions and impact attenuators and type; 4. Lay-bys for emergency, height controls etc. ahead of the portal; Emergency phones; 5. Buildings, installations and equipment for operational reasons (e.g. winter service). Appropriateness of location (distance from carriageway - more than 7m aside, distance from portal – not more than 50m), architectural design, access roads and other characteristics; 6. Paths for service or emergency vehicles to U-turn before the tunnel entrance. Grade separated (bidirectional tunnels) or at grade (unidirectional); 7. Need for refurbishment to avoid risks for users from degradation of outdated equipment.

3. Evaluation of the experience from the two first test sites

The joint road safety operations at the test sites of the first set of field tests, namely at Kennedy (RSI) and Krrabe (RSA/RSI), have already been performed in March and April 2016, respectively (see pictures in **Figures 3 and 4**).

In both cases, inspections in tunnels were held during night closures, while inspections during daylight were performed by official cars with appropriate signage, under ordinary traffic conditions and accompanied by the IM personnel. The length of the transition areas in the case of Kennedy tunnel was considered 432m on both sides of the tunnel and in the case of Krrabe tunnel 340m and 455m (one tube longer than the other).

The length of open road sections considered varied between 1200m and 2600m, depending on the local conditions and particularities of each test site (access/exit roads, ramps, alignment, etc.).

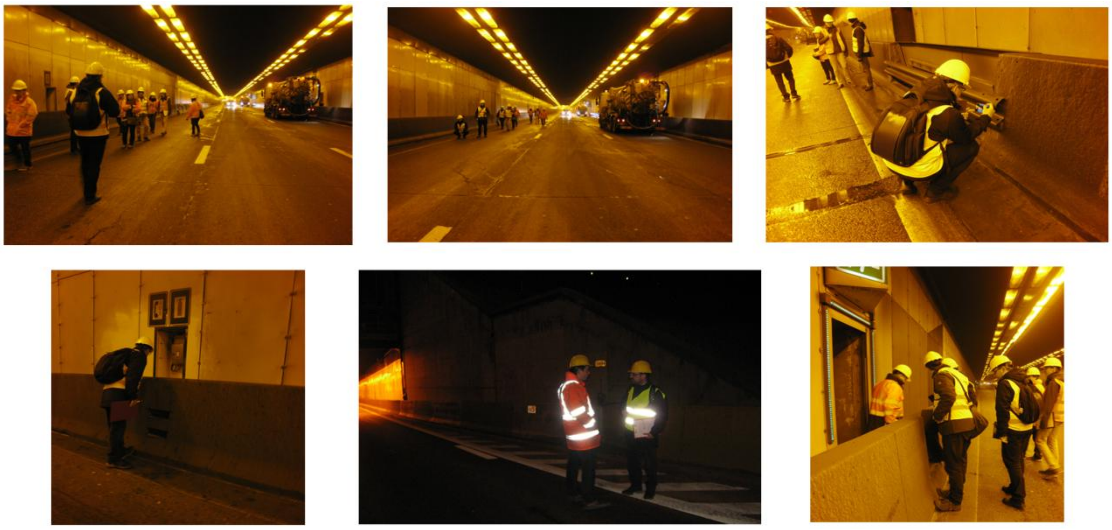


Fig. 3.
ECOROADS joint road safety operations at Kennedy tunnel, Antwerp

Fig. 4.
ECOROADS joint road safety operations at Krrabe tunnel, Albania

Both operations were considered successful, and their outcomes fed the discussions during the 2nd Workshop with stakeholders, held in June 2016. The third field test at Rennsteig in Germany was performed in mid-August 2016, having to take into account the following Workshop's outcomes for fine-tuning the Common Procedures that should be applied at the remaining test sites, of the 2nd set of field tests (ECOROADS Consortium, 2016b):

- the focus should be placed in tunnels and transition areas. Open roads should not be inspected, unless serious issues emerge from the preliminary analysis or if there is a specific written request by the IM. For this, the transition area length may be extended over the minimum value defined in the Common Procedures.
- External Observers, once admitted to participate in a field test, commit themselves to replace any eventual absent member of the Core Team, according to their expertise, and this should be taken into account while preparing the composition of the RSA/RSI Group of a field test.
- the Facilitators of the test sites shall request in advance all the video recordings available for the concerned infrastructure as well as any other historic record of accidents in tunnels and open roads.
- all the written and oral communication before, during and after the field tests must be strictly in English.
- the use of Checklists is compulsory and it is left to the Core Group to decide which parts of the Checklists shall be used at a field test.
- the IMs should provide their feedback, at least on the most important observations, within the requested deadline set by the Facilitator.

4. Conclusion – Further actions and the role of SEETO

The ECOROADS exercise differentiates from the formal procedures, in order to take advantage of its experimental character, to build on best practices and to provide solid and well documented outputs and recommendations. The common approach developed comprises a methodological framework that is based on most recent research and guidelines for RSA/RSI. The proposed tools are deviating somehow from the classic ones used, in order to cover the segmentation of road infrastructure as defined by ECOROADS, i.e. open roads, transition areas and tunnel interiors, and checklists for tunnels and transition areas, with focus on road users' safety, have been drafted (Miltiadou M. et al, 2016).

This approach has been applied during the first set of ECOROADS field tests and in its fine-tuned version is applied in the remaining three field tests. In the remaining time of the project (foreseen completion in May 2017), the performance of the last two field tests is scheduled for Autumn 2016, in order to discuss the results of the second set of the field tests during the next project meeting by the end of the year and formulate sound recommendations by the end of the project.

SEETO as a key-player for Transport Policy in the region of South East Europe, and with high concern on Road Safety, is the facilitator of all the field tests in the region (Albania, Serbia and the Former Yugoslav Republic of Macedonia). SEETO provides the possibility to national road safety experts from the region to participate in the joint road safety operations. Specifically, each time two experts from two different Regional Participants participate at one field test (apart from the experts of the host organization – Ministry/ IM/ Road Authority). Furthermore, SEETO, as the partner responsible for the Common Procedures definition, participates in all the field tests and undertook the important role of the Internal Observer of the project, ensuring the appropriate monitoring of homogeneous implementation of the procedures. Last, but not least, SEETO is involved in the task of formulation of the policy recommendations of the project, which is the overall target of the project towards improving road safety on open roads and in tunnels.

SEETO, as a regional transport organization which puts a great importance on Road Safety, will continue to lead and facilitate the work with the national administrations on their capacity building in the area of road safety audits and inspections, which is an area now recognized as one of the most tangible transport policy (soft) measures on the extended Core TEN-T in the Western Balkans, according to the High Level Western Balkan Summits held in Vienna and Paris in 2015 and 2016, respectively.

Acknowledgements

The authors wish to acknowledge the contribution of the project coordinator (FEHRL) and all the ECOROADS partners (AIPSS, ERF, ASECAP, ETSC and FEHRL third parties) for the cooperation in the framework of this project that brings important results for further consideration of the improvement of road safety in wider Europe and in the region of South East Europe. Moreover, they wish to acknowledge the constructive cooperation and the efforts of the Regional Participants for the organization of the field tests in Albania, Serbia and the Former Yugoslav Republic of Macedonia and for their active participation in the project activities and especially in the field tests.

References

Austrian Road Safety Fund - Federal Ministry for Transport, Innovation and Technology. 2014. *Road Safety Inspection (RSI) Manual for Conducting RSI*.

COWI for SEETO Regional Participants. 2014. *Support to the implementation of the Strategic Framework Programme of the South East Europe Transport Observatory (SEETO) – Technical Assistance – Road Safety Audit Handbook*.

ECOROADS Consortium. 2016a. *Common procedures, with the indication of the safety procedures*.

ECOROADS Consortium. 2016b. *Preliminary guidelines*.

European Community. 2004. *DIRECTIVE 2008/96/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on road infrastructure safety management*.

European Community. 2008. *DIRECTIVE 2004/54/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2004 on minimum safety requirements for tunnels in the Trans-European Road Network*.

Miltiadou, M.; Cela, L.; Gjorgjievski, M. 2016. Effective and Coordinated Road Infrastructure Safety Operations: Common procedures for joint operations at roads and tunnels. In *Proceedings of the 4th International Conference on Road and Rail Infrastructure,* ISSN 1848-9850, 877-883.

Nitche, P. 2010. PILOT4SAFETY RSA Training-Preliminary Part: Safety in road tunnels.

Norwegian Public Roads Administration – Directorate of Public Roads. 2014. *Road Safety Audits and Inspections*.

PIARC. 2003. *Road Safety Manual: Recommendations from the World Road Association*. ISBN 2840601583.

PIARC. 2008. *Human Factors and Road Tunnel Safety Regarding Users*. Reference 2008R17EN.

IMPROVEMENTS OF ROAD INFRASTRUCTURE AND SIGNALIZATION ACCORDING TO "ADAS" REQUIREMENTS

Ana Trpković[1], Branimir Stanić[2], Draženko Glavić[3], Marina Milenković[4]
[1,2,3,4] University of Belgrade, Faculty for Transport and Traffic Engineering, Vojvode Stepe 305, 11000, Belgrade, Serbia

Abstract: The past decade has witnessed the development of highly advanced systems for assisting drivers while driving. The main objective has been the improvement of safety of traffic participants, alongside all the accompanying positive performances of these systems. The biggest companies in the automotive industry have already begun to implement and test the most modern technological achievements in their vehicles. However, the effectiveness of the modern Advanced Driver Assistance Systems (ADAS) can be compromised if there is no interaction between the road infrastructure (horizontal signalization – road markings and vertical signalization – traffic signs) and the vehicles which use it. Despite the brilliant possibilities of ADA systems, which can save thousands of human lives, the desired results cannot be attained without the active cooperation between the road sector and automotive industry. Large investments in the development of cars and new technologies do not correspond to the resources allocated for improving the quality of the markings which drivers follow while driving. The question can be raised: Are today's roads sufficiently "readable" for modern vehicles? According to the conducted research, the performances of built-in cameras and sensors helping the driver to react to potential dangers are significantly reduced or completely neutralized if the signalization is improper and signs damaged. The impossibility of "reading" the markings on the road using ADAS compromises the reliability of these systems and their safe application in case the quality of traffic signalization is not appropriate. The paper will more closely present and explain the issue of road „readability", as well as the possibilities of overcoming this problem. In addition, the review of the previous research and work in this field will be provided.

Keywords: driver assistance systems, traffic signalization, safety.

1. Introduction

In many countries, improving the safety performances of vehicles has represented one of the most significant causes of the reduction of traffic accidents with fatalities in the last decade. On the other hand, there has also been significant investing in infrastructure and the actions related to seat belts, drinking alcohol and speed. Unfortunately, there are still traffic accidents resulting in 300,000 deaths and serious injuries annually in Europe, which represents a 2% loss of GDP (EuroRAP and EuroNCAP, 2011).

The recent successes regarding safety in the European Union are encouraging. However, if the "vision zero" strategy is to be achieved, it will be required to raise the level of each individual element of the system "driver – vehicle – road" in the following years. Figuratively speaking: "5-star driving in 5-star vehicles on 5-star roads" (ERF and EuroRAP, 2015). Thus, modern vehicles and roads have a crucial role in returning drivers into a safe driving "mode" when their human performance fails.

Modern cars have a significantly greater role in saving human lives than they had in the recent past. Due to various technological advancements, nowadays there are vehicles on the roads which can significantly assist drivers while driving and thus raise drivers' safety and the general safety. Today vehicles can warn, guide and direct via navigation systems and take control over the braking system in dangerous situations. Modern vehicles are equipped for "reading" roads in terms of interacting with other drivers and the surroundings and in terms of recognizing traffic signalization and specific road equipment elements. However, the heterogeneous vehicle fleet with drivers of different characteristics is found on European roads which are differently equipped and signalized. Thus, using the modern driver assistance systems should reconcile these variations, contribute to the feeling of safety and increase the general level of road safety. It has been predicted that as early as in 2025 half of the travel on Europe's roads will be in vehicles equipped with some of the advanced systems. However, even the most modern vehicles, and drivers, cannot function well if road markings and traffic signs are worn out, confusing, inconsistent, non-compliant with international conventions or even non-existent. It is evident that significant results cannot be expected if the development of technology and advanced systems is not in compliance with the development of infrastructure and road possibilities. Vast financial resources are allocated for the automotive industry, while this tendency is not of the same intensity when it comes to the investment in infrastructure. According to John Dawson, the chairman of EuroRAP UK, large amounts of money are spent for the development of safety technologies but little attention is paid to the quality of road markings and signs. This results in the impossibility of using all the potentials of advanced systems. Also, the safety can be compromised if basic traffic conditions are not fulfilled – i.e. the existence of quality signalization which can be "read" by some of the ADAS technologies applied in modern vehicles.

This topic had been disregarded until 2011 when the experts from two leading European organizations in the field of road infrastructure and safety, EuroRAP (European Road Assessment Programme) and EuroNCAP (European New Car Assessment Programme) worked together with the aim to connect the automotive industry and road sector. Their basic idea was to enable the comprehensive use of the potential of the new technologies applied in modern vehicles. In this manner, thousands of human lives could be saved across Europe and the world. The working group consisting of the

[1] Corresponding author: a.trpkovic@sf.bg.ac.rs

acknowledged experts prepared a consultation paper named “Roads That Cars Can Read” and provided basic guidelines for reaching this objective, which will be thoroughly described in the following text. It should be underlined that the European Union Road Federation (ERF) offered its help and support on this project. As a result, these two organizations were organized under the auspices of EuroRAP to investigate how the road markings and traffic signs manufacturers could collaborate with the European automotive sector represented by the European Automobile Manufacturers' Association (ACEA) to bring this idea closer to realization.
The basic question raised in the consultation paper is: How can road markings and signs be optimized and improved in order to maximize the potentials of ADAS? First, it was necessary to define the current requirements of the car manufacturers, as well as the ones which could be reasonably expected in the near future, in order to enable reliable and effective utilization of advanced systems and trustworthy „reading“ of the roads. It was also required to define the priority activities at the level of the network and applied technologies. Then, it was necessary to examine the differences in infrastructure elements on the priority roads, as well as their impact on the effectiveness of the applied driver assistance systems. Thus, the conditions were set for defining the guidelines for improving traffic signalization, markings and signs on the European road network.
In accordance with the above mentioned, this report identified local and national variations in standards for basic road markings and traffic signs which could be eliminated at low cost during normal cycles of replacing signs and renovating markings, if the existing standards on the European Union level are adopted and applied in all countries. This refers mainly to ensuring consistency in the width of white lines of the horizontal signalization and retro-reflecting characteristics of the materials applied on the carriageway. It also refers to the continuity of the horizontal markings, especially of the edges of roads. The signs of vertical signalization have to be consistent regarding fonts, colours, shape, sizing, in accordance with the international convention. The weaknesses of the main European roads’ infrastructure have been analyzed in the road safety research and ranking led by EuroNAP. At the moment, there are differences regarding road elements across Europe. Michiel van Ratingen, EuroNAP’s secretary general, believes that the existing road network has not been designed in concordance with new technologies because they did not exist at the time of construction. Also, national differences are significant; thus, for example, in Germany everything could function well, but if you travel to another country, the effectiveness of these systems’ use could decrease by 10%, 20% or even more, solely due to the lack of suitable signalization or other infrastructure limitations. (TTI, 2012)
It is a fact that the majority of travel and traffic accidents happen on Europe’s roads of economic importance which comprise just ten percent of the entire European road network. Bearing this in mind, this part of the European road network and the significance of its quality equipment and maintenance have been the centre of this project, with the aim of increasing the effectiveness of the advanced systems.
Generally, the combination of various manners of road maintenance and different national regulations regarding road markings and signs throughout Europe represent a major obstacle for the effective implementation of the ADAS technologies.

2. Driver assistance systems – advanced vehicle systems

The characteristics and possibilities of modern vehicles differ significantly from those of the cars that were produced in the recent past. The cars of today include systems for driver navigation, offer different traffic information, contain built-in systems for avoiding collision, adapting speed, night vision, cruise control, etc. All these advanced technologies have been implemented in order to ensure maximum safety and additional driving comfort.
Within these systems, two systems have been most frequently implemented and regarded as the most significant, and they demand the improvement of infrastructure:

1. Lane support system - (LSS), within which the following can be singled out:
    - Lane Departure Warning (LDW)
    - Lane Keeping Assistance (LKA)
2. Traffic Sign Recognition (TSR)

Each of the above mentioned systems assists the driver in a different manner.

2.1. Lane support system - (LSS)

The Lane Keeping Assistance (LKA) and the Lane Departure Warning (LDW) can “read” the road markings and give a visual, acoustic or tactile warning if the vehicle, suddenly, changes the lane. Drivers can feel like running over a rough surface even though there are no physical changes on the carriageway. The Lane Keeping Assistance System (LKA) gives the driver significant steering support.

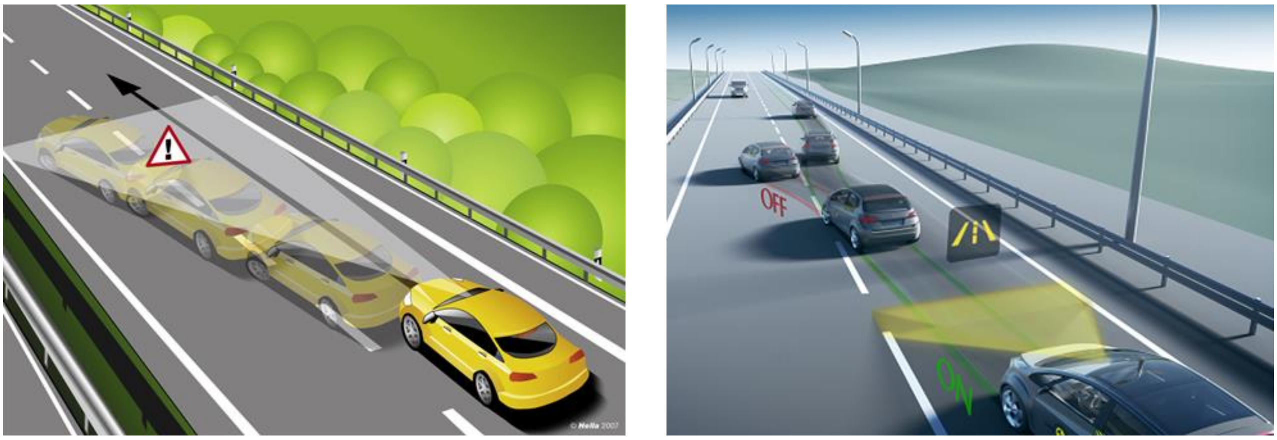


Fig. 1.
Lane Support System - (LSS)
Source: http://www.inautonews.com/wp-content/uploads/2009/10/lane-keeping.png

It is obvious that these systems demand for road markings to be visible, of good quality, same colours and dimensions, and this has not been fulfilled in the existing road network.

2.2. Traffic Sign Recognition (TSR)

Recognizing traffic signs is enabled by the built-in systems which can read and interpret various types of signs, including speed limit signs. Thus, within this group of advanced systems, Speed Alert Systems (SAS) are extremely significant and traffic signs play a major role in their effective functioning.

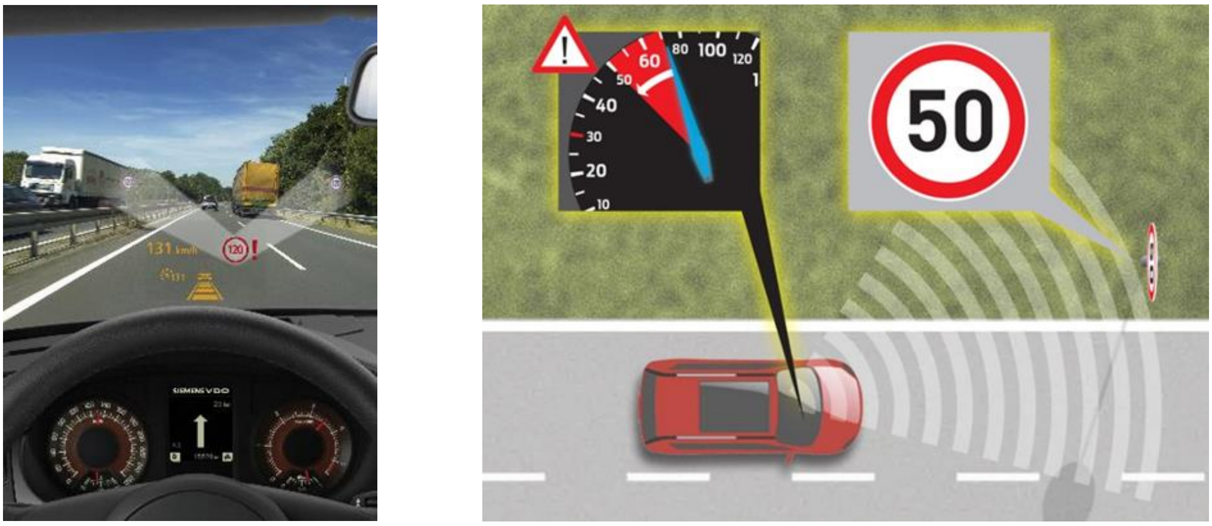


Fig. 2.
Speed Alert System (SAS)
Source: http://images.dailytech.com/nimage/2728_sc_upload_file_sv200608005_300dpi_1396442.jpg

Until recently, only the driver has absorbed the information given by road markings and traffic. The maintenance, consistency and uniformity of road markings are even more significant now that both drivers and vehicles have to “read” the posted traffic signalization. It is of utmost importance that the driver and the vehicle interpret road markings and signs in the same manner, since otherwise the safety would be in danger and consequences fatal.
The technology applied in ADA systems is similar to the human eye. It “reads” road markings and traffic signs, it assists the driver to keep in lane, keep on the correct side of the road and warns about potential hazards ahead. But like the human eye, the technology cannot work effectively if it cannot “see” road markings and traffic signs which are faded or hidden, or unclear or confusing. The mentioned advanced systems LKA, LDW and TSR “supplement” the human eye, guide and/or warn and thus ensure safe and comfortable driving.
The guidelines obtained as the result of research and analyses are primarily directed at the improvement of quality standards for road markings and traffic signs on the main European road network. Two key elements of road infrastructure which have to be adapted in order to optimize the effectiveness of ADAS in the vehicle are: road markings and traffic signs.

3. The improvement of road markings

The basic rule of the road markings' quality is: *road markings must be identically visible to the driver, day and night, and in all weather conditions* (Stanić B. et al, 1997). Their effectiveness depends on their luminance and the retro-reflectivity of the material, as well as on the surface where the markings have been applied. The European standards stipulate the minimum levels of retro-reflectivity of road markings in various weather conditions. The quality level a "good" road marking should be achieved for both wet and dry traffic conditions, which is technically feasible and cost effective in most European countries.

According to the requirements of advanced vehicle technologies, factors which can affect the operation and performance of lane departure warning (LDW) and lane keeping assisting (LKA) systems have been identified, and they are related to the road network infrastructure. According to their importance, these factors have been put in three categories:

- High Factors: road surface condition, worn out markings, multiple (confusing) road markings, old road markings which are not completely removed;
- Medium Factor: road gradient, road curvature, boundaries between several lanes;
- Low Factors: lane width, visibility;

Since road markings are applied on the road surface, it was required to define the above mentioned.

In order to obtain better road markings' characteristics, it is primarily required to improve and enhance the existing standards which road authorities have to implement in order to optimize driver assistance systems. They should be applied during the standard maintenance and replacement cycles, which would be cost-efficient and effective. On the basis of the collected data of interventions on the network and maintenance standards from a number of European countries, the ERF has defined the basic characteristics of a "good" road marking as a road marking whose **minimum performance level under dry conditions is 150 mcd/lux/m² and which has a minimum width of 150 mm for all roads**. For wet conditions, the minimum performance level should be 35 (European Union Road Federation, 2013) These requirements have been fulfilled in part of the EU member countries, so the application of this standard can be considered realistic, technically feasible and cost-effective.

Fig. 3.
New road markings
Source: http://www.geveko-markings.com/uploads/pics/ViaTherm-thermoplastic-road-marking-material.jpg

The consultation paper "Roads That Cars Can Read" provides the following guidelines and proposals for improving road markings:

- All roads should be properly marked and the markings maintained regularly to be clearly visible and not confusing;
- Using retro-reflective markings which are visible under all weather conditions;
- Synchronizing the colour and dimensions of road markings;
- Using continuous lines to delineate the edge of the carriageway;

These measures would be applied on the network of Pan-European roads which are economically significant. The implementation costs are mostly low if compared with the expected safety, while the feasibility is very high. The cooperation and harmonization between the member countries is requisite for some measures, such as the use of the continuous line for the edge of road, in order to ensure effective implementation.

4. The improvement of traffic signs

The Traffic Sign Recognition technology functions using built-in cameras which can “see” and “interpret” the traffic sign’s colour, shape, message, etc. However, in order to be effective, a sign has to be visible to both the human eye and the technology which is reading it. Thus, the principles of retro-reflectivity must be applied equally to traffic signs, i.e. the sign’s visibility is determined by the amount of the reflected light according to the European standard EN 12899.

Similarly to road markings, the factors impeding the effective recognition of conventional traffic signs have been ranked:

- High factors: vandalism/graffiti, sign position, hidden signs;
- High-medium factors: incorrectly positioned signs, the angle of position;
- Medium factors: the quality of the sign surface, inconsistent placement of the signs, differences in colour and shape;
- Low factors: confusion of multipurpose signs positioned at the same location, ambient illumination;

It should be noted that the group Variable Message Signs (VMS) causes difficulties to camera sensors. The major part of the European road network is equipped with VMS, so the requirements should be defined and proposed to be fulfilled by VMS in order to be accurately and easily read.

One of the major problems related to using new technologies in vehicles are the differences in traffic signs present throughout Europe (Table 1).

Table 1
Differences in basic traffic signs in Europe

Traffic signs	Great Britain	Greece	Netherlands	Poland	Serbia
STOP	STOP	STOP	STOP	STOP	STOP
Give way	GIVE WAY				
No entry for motor vehicles					

Source : http://www.euroncap.com/files/Roads-that-cars-can-read---0-41b5e8b7-ae0d-4fd0-abc3-0c4548cd697e.pdf

In order to use the potential of the advanced systems and reach the optimal performances of traffic signs recognition, some prerequisites must be met and they represent basic guidelines defined by the working group in the above mentioned consultation paper "Roads That Cars Can Read" (EuroRAP and EuroNCAP, 2011):

- Harmonisation of traffic signs across Europe (colours, shapes, fonts) with the Vienna Convention (Table 1)
- Standardization of European instructions for mounting signs, defining the number of signs, installation angle, etc;
- Use of more durable materials which do not lose their visibility over time;
- Regular maintenance of signs which ensures clear visibility in all weather conditions
- VTS must be developed so it can be “read” by advanced technologies as well as by the human eye;

The main aim of the application of these proposals for improving traffic signs is the more efficient use of ADAS systems and improvement of the general safety on the European road network. The costs of the implementation of these measures have been estimated as low, in comparison with the expected safety and efficiency benefits. The feasibility is high, except for the proposal referring to synchronizing the main traffic signs regulations which demands harmonizing the legislation at the highest level.

5. Conclusion

It has been predicted that until 2025 most people will travel in vehicles equipped with implemented advanced technology, which can “read” the road ahead. Due to the persistent improvement of some elements of the traffic system, modern roads and road infrastructure impede the process, i.e. it is difficult to integrate new systems into the existing infrastructure. Thus, the process of road and road infrastructure development has not been completed yet (Stanić B. et al, 2013). In the following period, the existing road infrastructure across Europe should be adapted to the requirements of intelligent vehicles in order to obtain their maximum effectiveness and safe traffic flow.

This paper offers a short review of the previous research and results in this field. It identifies the scope, feasibility, costs and limitations for improving traffic signalization which can be read by both drivers and advanced systems. Guidelines have been defined for improving traffic signalization and they should be conducted in the following period. These proposals can contribute to better interaction between vehicles and traffic signalization on the road. Some of the measures can be implemented immediately, some require further research before the application, and others can represent separate research projects which demand broader consensus of the interested parties and this can prolong the implementation.

In addition, the phenomenon of ageing of the European population should be underlined. It is expected that by 2020 approximately 25% of the drivers on European roads will be older than 65 years. Due to their decreased abilities, this category of users will need clear and visible guidance on the road. These facts indicate the necessity of rapid reaction and adaptation of the road infrastructure.

The recommendations set out in this paper represent cost-effective proposals which, if implemented, would bring significant reductions in traffic accidents with casualties and fatalities and would improve driver comfort. It should be noted that most of the proposed measures are considered to be relatively "inexpensive" in relation to the benefits which could be gained. In this manner, the existing roads would be properly adapted and prepared for the era of intelligent vehicles and the new structure of users.

References

ERF and EuroRAP. 2015. Rainvision project. Roads that cars can read - Presentation. Available from Internet: <http://www.erf.be/images/RAINVISION/6._SS_Rainvision_March_2015.pdf>.

European Union Road Federation (ERF). 2013. Marking the way towards a safer future. Available from Internet: <http://www.erf.be/images/ERF_Paper_on_Road_Markings_Released.pdf>.

EuroRAP and EuroNCAP. 2011. Roads that cars can read – A consultation paper. Available from Internet: <http://www.euroncap.com/files/Roads-that-cars-can-read---0-41b5e8b7-ae0d-4fd0-abc3-0c4548cd697e.pdf>.

Stanić, B. et al. 1997. *Traffic design - road markings*. Faculty of Traffic and Transportation, Belgrade. 153 p.

Stanić, B. et al. 2013. New ideas and potentials in traffic design and implementation of the road equipement. *In Proceedings of the IV International Conference "New Horizons 2013"*.

Traffic Technology International (TTI). Feb/March 2012. Active measures, 17-23. Available from Internet: <http://www.traffictechnologytoday.com/magazine.php>.

MODELING OF DAILY TRAFFIC VOLUMES ON URBAN ROADS

Ladislav Bartuška[1], Vladislav Biba[2], Rudolf Kampf[3]
[1] *Czech Technical University in Prague, Department of Logistics and Management of Transport, Prague, Czech Republic*
[2] *The Institute of Technology and Business in Ceske Budejovice, Department of Informatics and Natural Sciences, Ceske Budejovice, Czech Republic*
[3] *The Institute of Technology and Business in Ceske Budejovice, Department of Transport and Logistics, Ceske Budejovice, Czech Republic*

Abstract: The traffic volume is frequently used as a measure of road capacity. For many types of roads significant changes in traffic intensity occur within 24 hours a day. If the traffic volumes are measured during the day at hourly intervals, usually happens that the course of traffic volumes during the day has two maxima – morning peak hour and another peak hour in the afternoon. The authors of the article deal with modeling of the course of daily traffic volume using known probability distribution, while the authors use data obtained from real measurements of traffic volumes on the various categories of roads. In the paper the authors proposed procedure that can be applied to determine the resulting daily traffic volumes from short-term measurements of traffic volumes. Proposed procedure is suitable for urban planning, construction and upgrading of roadways or land-use planning decisions, while it is necessary to plan the construction of road infrastructure on the basis of prognosis of road traffic.

Keywords: AADT, traffic volumes, individual car transport, traffic statistics.

1. Introduction

Traffic volume indicates the use and the capacity of road infrastructure. In traffic engineering the traffic volume is generally stated as so-called Annual Average Daily Traffic (abbreviated AADT) for the section of the roadway in both travel directions in the number of vehicles per day, i.e. 24 hours. AADT is the total volume of vehicle traffic of a highway or road for a year divided by 365 days.
Traffic volume is measured by manual or automated counting of vehicles on the road section. Since the traffic survey is generally time-consuming action, mostly a short-term vehicle counting is carried out (usually a few hours in the morning and in the afternoon rush hours in one day), based on which we calculate Daily Traffic Volume and Annual Average Daily Traffic, together with other transport engineering indicators (for example Design Hour Volume). In the Czech Republic the method given by the Technical Conditions no. 189 (2012) is used to recalculate the values obtained by the short-term traffic survey (vehicles counting). Similarly, the methodology for detecting traffic forecast in the future period is introduced (TP 225).
Determining and subsequent forecasting of traffic volumes serve as a basis for the designing and planning of road construction, for the processing of concepts for the development of the road network, plans for construction and repair, maintenance planning, documentation of road structures, protection solution against excessive noise, etc. In the field of traffic-engineering traffic volume is an important aspect, which also serves to develop models of the transport network and simulation of its load and to assess the capacity of roads and of level intersections. It is therefore a very important input in many applications and it is necessary to determine traffic volumes to create models that reflect the actual state of traffic on the road network In the next chapters the authors deal with modeling of the course of traffic intensity within 24 hours by using Gaussian curves. By this method ideal daily traffic intensity on specific road can be modeled from the values obtained by short-term traffic counting (Bartuska, 2015).

2. Current methodology to determine AADT in Czech Republic

The current methodology as outlined in TP 189 is used to determine the annual average daily traffic volumes on the basis of short-term traffic surveys. In practice this means, that the traffic volumes can be measured (vehicles counting) in the profile of the roadway in the range of several hours in one day, and on the basis of the hour traffic volumes daylong intensities (24 hours within that day) can be calculated using conversion coefficients for the rest of hours of a day. Thereafter the weekly variations have to be taken into account – The daily average within the week (conversion coefficients for 7 different days) is determined. Finally, monthly variations are taken into account and on the basis of conversion coefficients the AADT is calculated (Freimann, 2004).
Particular above-mentioned conversions are carried out using conversion coefficients which are determined from long-term research for specific categories of roads, days of the week, time of the year and for specific types of vehicles as well. These coefficients are listed in TP 189 "Determination of traffic volumes on roads (II ed.)" from June 2012. Formula for determining the standard AADT on the basis of the coefficients is as follows (TP 189, 2012):

$$RPDI_x = I_m \,.\, k_{m,d} \,.\, k_{d,t} \,.\, k_{t,RPDI}\ , \tag{1}$$

[1] Corresponding author: bartuska@mail.vstecb.cz

Where; $RPDI_x$: Annual Average Daily Traffic to be determined (AADT) [cars/24 hours within day], I_m: traffic volume of a given type of vehicle identified during the traffic survey [cars/traffic survey duration], $k_{m,d}$: conversion coefficient of traffic volume acquired during the survey to daily traffic volume [-], $k_{d,t}$: conversion coefficient of daily traffic volume within the day of survey to average daily traffic volume within the week (all seven days in a week) [-], $k_{t,RPDI}$: conversion coefficient of weekly average daily traffic volumes to an annual average daily traffic volume [-].
The authors in another part of the paper deal with the daily variations in traffic, especially the extent to which the current values p_i^d can be applied to determine the daylong value of traffic volume, which constitutes the first step towards determining the final AADT. Values p_i^d indicate the percentage of hourly traffic volumes *i* on total daily traffic volume and can be used to determine coefficient $K_{m,d}$ (TP 189, 2012):

$$K_{m,d}=100\% / \sum p_i^d \ [-] \qquad (2)$$

Where; $\sum p_i^d$: combined share of hour traffic volumes within the duration of traffic survey to total daily traffic volume [%].
Values p_i^d are given in the methodology TP 189 for the types of vehicles, the character of traffic on the road and the time of year and were determined from long-term measurements. Values $k_{d,t}$ a $k_{t,RPDI}$ can be obtained analogously in a similar way as the coefficient for conversion to day variation $k_{m,d}$.

3. Daylong traffic volume on urban roads – theoretical approach

The authors conducted a short-term manual traffic counting on the II. class road going throw the city (according to the Czech categories of roads - Law No.13 / 1997 Sb) in order to demonstrate the calculation of daylong traffic intensity from the short-term survey using daily variations determined in the methodology TP 189. Traffic survey was carried out in spring workday in one point of the road and the vehicles were summed overall, regardless of the individual categories. The following table shows the resulting number of vehicles according to hourly intervals (Table 1).

Table 1
Number of vehicles in hour intervals obtained from traffic survey and hourly traffic volume ratios p_i^d determined by the methodology TP 189 for II. class roads

Hour	Number of vehicles	hourly ratios p_i^d (TP 189)
07:00-08:00	580	6,79 %
08:00-09:00	956	6,63 %
09:00-10:00	838	6,34 %
10:00-11:00	856	6,17 %
Total	3 364	25,93 %

Source: Authors

As mentioned in the previous chapter, hourly ratio p_i^d is the percentage of the hourly traffic intensity on a total-daylong volume of traffic (values are given in the methodology TP 189 and in this case, the values are relevant for the spring period, vehicles in total and for the II. class road). Daily traffic intensity should thus be determined for vehicles in total by using the equation:

$$I_d = I_m \, . \, k_{m,d}, \qquad (3)$$

Where; I_d: Daily traffic volume within the day of traffic survey [cars/24 hours within day], I_m :Traffic volume determined within the traffic survey [cars/duration of traffic survey], $K_{m,d}$:- conversion coefficient of traffic volume acquired during the survey to daily traffic volume [-].
We can now determine the conversion coefficient $k_{m,d}$ from the previous chapter (equation 2) when the result is $k_{m,d}$ = 3,8565. Daylong traffic volume should be therefore I_d = 12 973 vehicles.
If we apply an hourly percentages (ratios p_i^d) on the determined daily traffic volume, we get the ideal course of the traffic intensity on the roadway throughout the day. From this perspective it is evident that the longer the short-term traffic survey, the more accurate the calculation of daily traffic volume and consequently the calculation of AADT. For most of the transport engineering applications the duration of the survey about 8 hours at appropriate times of peak hours (usually chosen time 7:00-11:00 and 13:00-17:00 during weekdays) is sufficient, when it can be expected to achieve the deviation from the actual AADT to 10%.
The following chart shows course of the traffic intensity created on the basis of number of vehicles counted during a short survey and by using percentage of hourly ratios within the working day.

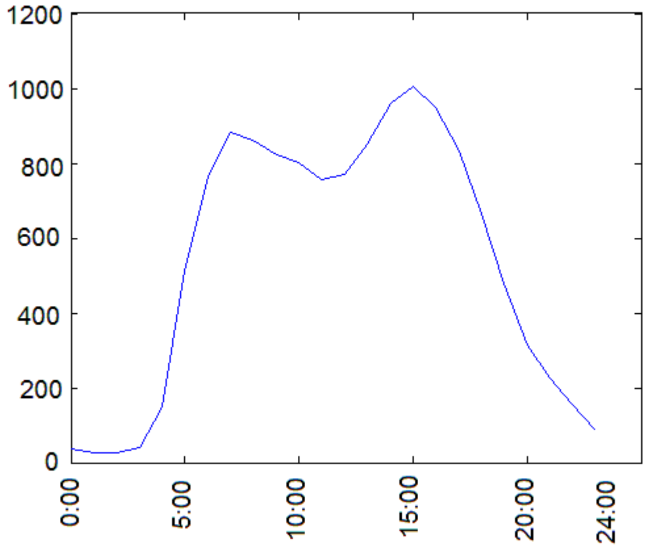


Fig. 1.
Hour traffic volumes within a day on II. class roads (according to the Czech methodology TP 189)
Source: Authors

This procedure is considerably simplified for the purposes of demonstration in this article. Methodology TP 189 is much wider due to the fact that in the calculations additional factors are taken into account, but for purposes of this article these factors are irrelevant.

4. Creating the model of daily traffic volumes

To create a model of all-day traffic intensity on selected roads it was necessary to carry out a long-term traffic survey. For three working days (Tuesday - Thursday) the number of vehicles on selected II. class roads (urban roads connecting suburban areas with the rural areas) by automatic detectors was detected. The automatic radar based traffic detection Sierzęga SR4 was used for traffic survey with appropriate software, which can evaluate other important traffic characteristics acquired by device (vehicle speed, frequency, distance between vehicles, etc.). The data from long-term survey were averaged and divided into 15-minute intervals within the specific day (Bartuska, 2015).
In our opinion, time development of traffic volumes can be described by a function

$$I_t = N_1 \cdot e^{-\frac{(t-t_1)^2}{s_1}} + N_2 \cdot e^{-\frac{(t-t_2)^2}{s_2}} \tag{4}$$

Meaning of the parameters in this formula is as follows: t_1 and t_2 are time moments when maxima of traffic intensity occur. We suppose two maxima during a day (morning and afternoon rush hours). Parameters s_1 and s_2 describe length of time intervals of maxima and, finally, N_1 and N_2 reflect traffic intensities in maximal points (Douglas, 2003).
Function given by the previous formula is, in fact, a sum of two different Gaussian functions. Recall that the Gaussian function is given by formula

$$y = \frac{1}{\sqrt{2\pi} \cdot \sigma} \cdot e^{-\frac{(x-\mu)^2}{\sigma^2}} \tag{5}$$

with parameters μ and σ (σ > 0). This function is important especially in mathematical statistics, where it describes probability density of normal distribution. Gaussian function have one maximum, which occurs at point μ on x-axis. We assume that the traffic intensity have two maxima during a day, therefore we use a function which is sum of two Gaussian functions and, consequently, have two maxima along x-axis. Moreover, morning and afternoon maximum can be of different heights, therefore we use parameters N_1 and N_2 (Douglas, 2003).
From the data divided to 15 minutes intervals we get the function

$$I_t = 178.9 \cdot e^{-\frac{(t-9.22)^2}{8.157}} + 236.3 \cdot e^{-\frac{(t-16.33)^2}{25.65}} \tag{6}$$

Calculations were done using software MatLab that provides functions for curve fitting. Software uses iteration methods - using least squares method would be not appropriate in this case. Original data in 15 minutes intervals and model function given by MatLab are depicted in figure 2.

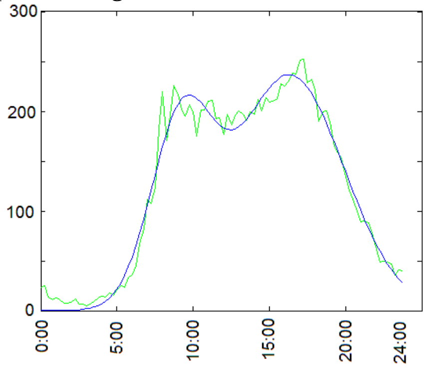


Fig. 2.
Average 15-min traffic volumes within a day on a urban II. class road: green – actual data, blue - model
Source: Authors

When comparing original data with model function, it can be observed that the function closely fits the data during intensity increase in the morning and also decrease at the afternoon and evening hours. Also note that, in reality, decrease during noon is not as obvious as in the model function.
Trend function is least precise in hours after midnight. This is caused by the fact that the minimum traffic intensity occurs around 3:00 and not at the midnight. From mathematical point of view, it would be better to model the traffic intensity from 3rd hour of one day to 3rd hour of a following day. Traffic intensity in these hours is very low (when compared to the working hours), therefore this inaccuracy can be neglected.
Daily traffic volume in the measured section of the road was 12 098 vehicles in average, trend function gives 12 039 vehicles (this value can be obtained using numerical integration).
With given trend function, we tried to model traffic intensity during 24 hours on a different road of the same type. For this prediction, we use only data acquired in 4 hours during morning peak (7:00 – 11:00). We estimate that the time moments of maxima are same for all roads of the same type. Figure 3a shows traffic intensity predicted by trend function (blue line) and real situation (green). Red color in the graph highlights the time period 7:00 – 11:00. Daily traffic volume on the measured road was 13 500 vehicles, prediction by our trend function is 13 687 vehicles. (Compare this with the result given by the methodology TP 189 according to section 3.) Same algorithm was used to predict traffic intensities on three other roads of various types (figures 3b – 3d).

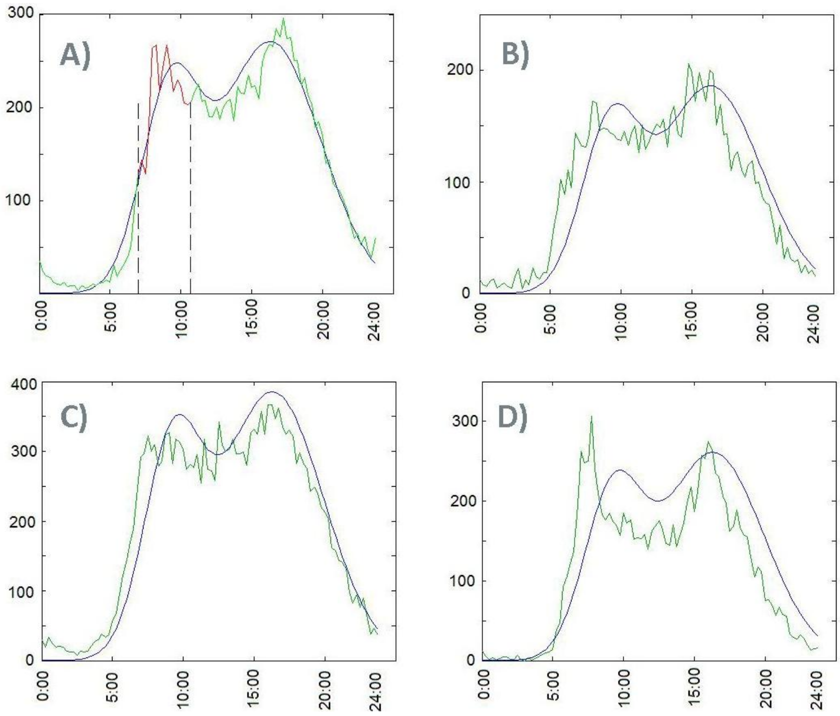


Fig. 3.
15-min traffic volumes within a day on a urban and regional roads: green – actual data, blue – intensity predicted by model
Source: Authors

It should be noted that the authors conducted traffic survey in the first three cases on II. class roads in urban areas and in the fourth case it was an all-day traffic survey on the road of the same category, but outside the city in a rural area (road D, fig. 3 d). From these measurements it is evident that the model cannot be used on the roads with different characters of traffic, although it is the same category of roads. Methodology TP 189 is considering a comprehensive set of coefficients for vehicle counting on all of these roads of the same category. The number of vehicles determined on the monitored road section with the designation “D” throughout the day is in fact significantly less than what used model calculates from short-term measurements, but also what the methodology TP 189 calculates. To properly predict the traffic intensity on this type of road (similar traffic character), long-term data are needed and new trend function for this traffic character must to be created. All-day traffic volumes on four road sections are shown in Table 2.

Table 2
Total numbers of vehicles within 24 hours on II. class roads in urban and rural areas

	real daily traffic volume	**theoretical daily traffic volume (TP 189)**	**theoretical daily traffic volume (model)**
A	13500	12973	13687
B	9268	8909	9401
C	19006	18454	19473
D	11165	12503	13194

Source: Authors

5. Conclusion

The authors proposed a model for calculating the daily traffic volumes on particular roads using the probability distribution. From the conducted long-term survey (vehicles counting) the model of daily intensities was developed, which was applied to the resulting data from short-term measurements on different roads of same category (survey duration of 4 hours in the morning rush hour). Based on the model, it was possible to calculate the theoretical daily traffic volumes on the roads of the same category but different traffic characteristics. It was mainly the urban character of traffic and inter-town regional traffic character.

Follows from the above it is evident that as a model of Gaussian curves, neither TP methodology 189 cannot be used on a road of the same category with the heterogeneous character of the traffic. For more accurate results of theoretical daily traffic volume and subsequent Annual Average Daily Traffic (AADT) calculated from short-term surveys the additional factors should be taken into account, affecting more or less the character of the traffic on the specific road in network (Hanzl, 2016). The daily traffic volume is traffic load index on road section in particular working day of the year. For the calculation of AADT weekly and annual variations should be considered and proposed model can take these values into account after enlargement. However, the model doesn't determine the peak hour traffic intensity (Designed Hour Volume), which is significant for comparison with the capacity of the infrastructure and is needed for other traffic-engineering applications. The authors will deal with determining the optimum calculation of the DHV in their subsequent work (Kampf, 2004).

References

Bartuska, L.; Stopka, O.; Lizbetin, J. 2015. Methodology for Determining the Traffic Volumes on Urban Roads in the Czech Republic. In *Proceedings of the Transport Means - 19th International Scientific Conference on Transport Means.*

Freimann, F.; Kampf, R.; Tilkeridis, D. 2004. *Analysis of Approach to Traffic Infrastructure Development. In: Railways as part of the Integrated Transport System*, CVUT - Transport Faculty, Prague, Czech Republic.

Technical Conditions no. 189 2012. “Determination of traffic volumes on roads (II. edition)”, EDIP s.r.o.

Czech Republic - Law No.13 / 1997. Sb., “o pozemních komunikacích”, as subsequently amended.

Bartuska, L.; Cejka, J.; Caha, Z. 2015.The application of mathematical methods to the determination of transport flows, *Nase More*, 62: 91-96.

Douglas, M.; Runger, G.C. 2003. *Applied Statistics and Probability for Engineers, 3rd editon*, John Wiley and Sons Inc, New York, U.S.A.

Hanzl, J.; Bartuska, L.; Rozhanskaya, E.; Prusa, P. 2016. Application of floyd's algorithm on transport network of south bohemian region, *Komunikacie*, 18(2): 68-71.

Kampf, R. 2004. Criteria for the Quality Classification of Investments. In *Management of Production Systems*, ed. Presov - Technical University in Kosice, Slovakia.

DEVELOPING A LOCATION MODEL FOR FAST CHARGING INFRASTRUCTURE ON MAJOR HIGHWAYS

Abdolmatin Shirmohammadli[1], Dirk Vallée[2]

[1,2] Institute of Urban and Transport Planning, Department of Civil Engineering, RWTH Aachen University, Mies-van-der-Rohe-Strβe 1, 52074 Aachen, Nordrhein-Westfalen, Germany

Abstract: During recent years, establishment of E-Mobility gained a significant attention of politicians and eco-friendly groups as a sustainable solution in transport sector resulted from increasing greenhouse gases and local issues such as emissions and noise. Nevertheless, the acceptance of E-Vehicles among people was not so promising due to several issues especially the limited range of E-Vehicles, long charging time and lack of enough public charging stations on the highways. Consequently EV's usage is limited only to the daily inner-city trips but not to the longer-distance weekend or vacation trips. The objective of this research is to develop an efficient and transparent location finding model for Fast Charging Stations (FCSs) on the highways based on user's point of view to cover this problem. Different use-case scenarios were developed in the proposed model which are based on traveler's charging behavior e.g. state of charge of battery by arrival and departure or range anxiety as well as their travel behavior in term of their detour acceptance to reach a charging station. Determination of optimal location for FCSs meets different user behavioral assumptions in each use-case scenario. Apart from the use-case scenarios, significant criteria were investigated and utilized in the location model such as traffic volume of commuters and foreign travelers. The input data such as highway network and existing charging stations as well as the location finding criteria and their weights are analyzed, edited and depicted in form of different layers in Geographic Information System (ArcGIS software), which enables the users to spatially couple the different information together. The proposed location model helps the authorities and investors to establish an appropriate network of FCSs on the major highways and increase the acceptance of EVs which could be considered as a midterm solution for the limited range of E-Vehicles before it is technically solved.

Keywords: e-mobility, location model, fast charging station, highways.

1. Introduction und literature review

Nowadays, the climate change is one of the most important and complex issues which gained a significant attention of different groups and societies. In this context there are plenty of efforts and policies in national and international levels to improve the efficient energy consumption in different sectors such as industry, household and transport. The potential of optimizing the energy consumption in transport sector attracted different groups of stakeholders which resulted in clean and high efficient technologies in automotive industry such as hybrid, hydrogen and Electric Vehicles (EVs). E- Mobility, as an important component of sustainable mobility development, cleans up the local air pollution, slashes global CO2 emission and through efficient energy consumption in compare with conventional internal combustion engine vehicles, allows the growing renewable energies play even more significant role in reducing the fossil fuel dependency.

Due to these excessive ecological advantages, the EVs (battery or plug-in hybrid) are expected to have a major impact on car industry however, its acceptance among people was not so promising by today. There are still significant barriers such as resistance of consumers to new and unproved technologies (Egbue, 2012), high purchase price and lack of public charging stations. Beside the mentioned reasons, technical deficits such as limited range and long charging time, which limits EV's usage mainly for short inner city trips (Frenzel et al., 2015 and Rezvani, 2015), are still significant barriers for slowing down the widespread adoption of EVs. Competing against internal combustion vehicles which can be filled up in just a few minutes and can cover a range of several hundred kilometers per tank, the biggest obstacle for spreading the EVs seems to be their range and the time it takes for an EV battery to be charged because the feeling of having a limited range and a longer fueling time isn't one that most of users are comfortable with. Capturing new groups of EV users requires fulfill this gap and enabling users to have longer intercity trips which needs at least one intermediate stop for recharging the battery. The current paper highlights the importance of a comprehensive fast charging infrastructure on highways in order to address this major concerns. Whereas the users could make use of their activity time for their daily routine activities in the urban areas such as shopping and leisure activities in order to charge their EVs, the travelers on major roads aim to reach the destination as soon as possible and there is no routine activity during the travel time. Based on this assumption, there is no usage for slow or normal charging infrastructure on the major roads but only for Fast Charging Stations (FCSs).

Whereas the conventional charging process takes several hours the fast charging technology could load the battery of EVs within 30 till 60 minutes (depending on efficiency of charging stations and battery capacity) which enables traveling a distance beyond the limited range of EVs. In this regard, FCSs could be considered as an intermediate solution for the limited range of EVs and long charging time before it is technically solved. However, high installation cost of FCSs is a significant barrier to establish an extensive fast charging network and in this regard, the determination of optimal location for fast charging infrastructure plays a key role to ensure their long-term profitability and operatability. This research introduces an efficient and transparent location model in order to find the optimal location of FCSs on the major highway network. The problem of determining the optimal location for FCSs could be approached from different point of views. Some researchers tried to optimize the electricity supply grid considering

[1] Corresponding author: shirmohammadli@isb.rwth-aachen.de

some objectives such as reducing power loses or/and reducing the voltage deviation (Wang, 2013; Mohsenzadeh, 2015; Bayram, 2013). Some others investigated the economics and business cases of this technology focusing on profitability objectives such as return of investment based on some assumptions and scenarios e.g. development and penetration of EVs in the market, utilization level of charging stations and the price of electricity in the charging stations (Wirges, 2012; Schroeder, 2012; Zhu, 2016). Some other researchers investigated the optimal location of (fast) charging infrastructure based on user's behavior, which is the case in this paper as well. This approach is generally divided into two categories of major highways and urban areas. Concerning the limited range of EVs and perceived range anxiety of users for long-distance trips, the provision of FCSs on the major highway have been the first priority of many researches and policies in the recent years (Nicholas, 2012; Sathaye, 2013; Zhang, 2015; Li, 2016). The presented location model in this paper focuses on covering the demand on major highways and explores this problem from user's behavior point of views as well as transportation criteria.
The reminder of this paper is organized as follows: Next chapter gives an insight into important characteristics of FCSs and EVs, especially those which are related to travel and charging behavior of EV users, so that the utilized criteria in the model is more comprehensible. Chapter 3 introduces the algorithm and calculation method of the model including input parameters, utilized criteria in the model and their weighting system. The proposed model will be implemented by means of Geographical Information System Software (ArcGIS Software) in the real case of Germany and the results will be presented in chapter 4. The last chapter is dedicated to discuss the validity and plausibility of the results and other possible application of the proposed model.

2. Overview of some technical attributes

The main technical characteristics of charging infrastructures and EVs will be introduced in this chapter without investigating them in detail which gives an overview about the utilized criteria and parameters in proposed location model.

2.1. Range of Electric Vehicles

The range of EVs is an important criterion in the proposed location model which is described in more detail as follows. The official announced range of an EV is measured under a very restricted standard conditions so that the range of different EVs are comparable to other EVs. However, the actual range of EVs in real driving conditions may be much less than the laboratory announced range. Environmental Protection Agency in United States (EPA[1]) simulates the real-word driving conditions and estimates the range of EVs based on a wide range of factors such as driving style and behavior of drivers, utilizing additional energy consumer devices such as air condition, radio, differences between urban or highway trips, etc. Although the EPA's estimations are not perfect however their approximation provide a reliable basis for comparison of real-word range of different EVs. Table 1 presents the range of some selected EV models measured by EPA:

Table 1
Comparison of measured range of EVs for a fully charged battery, source: EPA

EV Model	Nissan leaf[2]	Chevrolet Spark EV	BMW i3	Mercedes-Benz B250	VW-e-Golf	Tesla Model S[3]
Max. Range (km)	135-172	131	130	140	134	376-435

Another important factor which reduces the Range of EVs is the charging behavior of users because a full-charged battery is considered in calculation of mentioned ranges in Table 1 which is not a realistic supposition. Smart et.al. (2013) show that only 40% of charging processes run till full-charge and the majority of users do not charge their battery completely. Therefore the above mentioned ranges should be adjusted in accordance with charging behavior of users. Since this research does not have enough data about charging behavior of users, it is assumed that the state of charge of battery by departure is 80% which is a realistic assumption based on charging time of a battery using a FCS.

[1] Environmental Protection Agency of US https://www3.epa.gov/
[2] 24-30 kWh battery
[3] 70-90 kWh battery

Table 2
Comparison of range of EVs considering the charging behavior of users

EV Model	Nissan leaf[1]	Chevrolet Spark EV	BMW i3	Mercedes-Benz B250	VW-e-Golf	Tesla Model S[2]
Max. Range (km)	108-138	104	104	112	107	300-348

In order to cover the charging demand of all EV models, this research considers the least available range and according to the Table 2, the minimum range of EV considering charging behavior is equal to 104 km. This range will be utilized in order to develop different scenarios in the presented location model in the following chapters.

2.2. Fast Charging Infrastructures

The charging infrastructures could differ depending on charging method and technology, input electricity type and charging performance. These characteristics and also capacity of battery influence mainly the charging time of EVs that could vary from 30 minutes until twelve hours. Charging methods could be inductive in which the energy is transferred via a magnetic field, battery swapping in which the battery is not charged directly but the depleted battery is replaced with a fully charged one or the most common method of cable charging, which is equipped with a connector on the end of charging cable that can be coupled to a socket on the EV. In addition to transferring the electricity in cable charging method, the coupling could allow additional features such as starting or stopping the charging operation or energy meter. Regardless of charging method, the power levels of charging infrastructure play a key role for determining the charging time of EVs which can be divided into three charging levels. Level 1 is the lowest common voltage level available and considering the average capacity of a battery as 20 kWh, it takes roughly 6-8 hours to fully charge an empty battery. Utilizing a single or three phase AC electricity source with 3.7-22 kW power the Level 2 charging stations could reduce the charging time up to one hour. Both level 1 and 2 chargers provide AC current which should be converted to DC in order to charge the battery. It happens via an on-board AC/DC rectifier in the EVs, which take input power from an AC source and converts it to DC current. The AC/DC conversion process via on-board rectifier of EVs causes a large loss of power, therefore the level 3 charger was developed which supply the battery of EVs directly with high DC power. Although the FCSs could also work with AC electricity, but generally the term “Fast Charging Station” refers to those chargers, which provide DC electricity. According to EU definition (directive, 2014/94/EU), charging stations which transfer the electricity with a power of more than 22 kW are labeled as fast charging stations and below than this power refers to normal powered stations. The most installed FCSs in the practice have the power between 50 kW and 120 kW which are able to charge a 20 kWh battery to 80 percent of its capacity within 15-30 minutes. Many studies explored and reviewed the technical features of DC charging stations in detail (e.g. Channegowda, 2015) which is not the case in this paper. Another important characteristic of EVs is their plug-in system. Most of the EVs have a standard connector based on the SAE J1772 standard which enable them to use Level 1 or Level 2 chargers which eliminate drivers concerns about whether their vehicles are compatible with charging infrastructure or not. However, considering the level 3 chargers, there are three DC plug-in charging types by now: The CHAdeMO system developed by the Japanese auto industries which provides a current source up to 62.5 kW and it is capable generally with their EVs as well as Peugeot and Renault; Supercharger which provide 120 kW power to Tesla EVs and Combined Charging System (CCS) introduced by German engineers which utilizes a single connector allowing 50+ kW be delivered to the battery of car makers companies of BMW, Daimler, Ford, General Motors, and Volkswagen. The main point with the mentioned fast charging systems is that they are not compatible with all EVs which is an important drawback from users’ perspective.

[1] 24-30 kWh battery
[2] 70-90 kWh battery

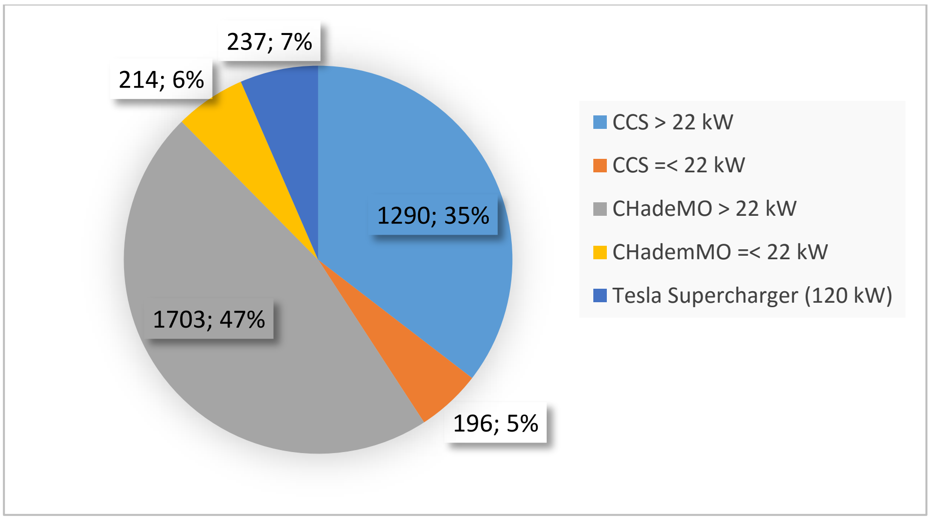


Fig. 1.
Number and share of existing FCSs in Europe according to charging power and plug-in system
Source: http://www.goingelectric.de/stromtankstellen/statistik retrieved at 01.07.2016 (own illustration)

3. Methodology

The optimal location of FCSs on the highways in this research is determined according to following steps:

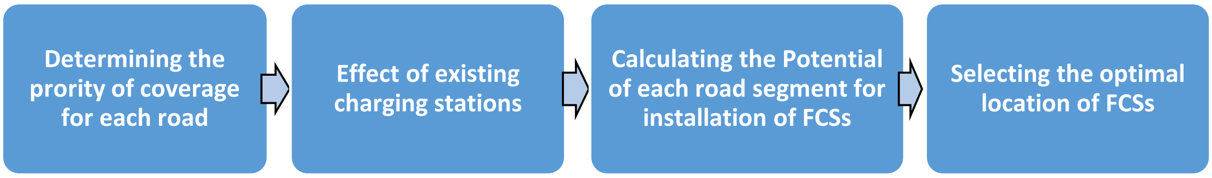


Fig. 2.
Main steps of location model for determining the optimal location of FCSs

The first step investigates and determines the priority of each road segment for covering with FCSs, which depend on different criteria and their weights. The effect of existing charging stations on potential of each road segment will be investigated in the second step. The potential of each road segment will be calculated in third step, which is based on priority of each road and influence of existing charging stations. The optimal location for new charging stations will be determined based on calculated potential in the last step. It should be regarded that the results of this algorithm could vary according to different assumptions about user behavior, parameters and weights for criteria. The input data of the location model are in geospatial vector data of shapefile format, which contains different attributes in their attribute table.

3.1. Coverage Priority of each road segment

This section differentiate the major roads in term of their priority for covering with FCSs. The coverage priority could be determined based on wide variety of criteria. Due to data gathering difficulties and also in order to avoid too much model complexity, this research utilizes the following three criteria for determine the coverage priority: daily traffic volume on roads, importance of roads as part of international road network and highway network accessibility. An important point for determining the coverage priority is that the importance of mentioned criteria could be different depending on goals of project or decision-makers' opinion. For example, if the main goal is to provide the FCSs to as many EVs' users as possible (efficiency goals), so the criterion of "daily traffic volume" should get a higher weight in compare with other two but if the provision of service to poorly accessibly areas are more important (equity goals), then the criterion "autobahn accessibility" plays more important role for determining the coverage priority.

3.1.1. Daily Traffic Volume

It is assumed that more traffic volume on a road results in more EVs (or potential EVs) on it and therefore the demand for FCSs will be higher. Considering this assumption, the data of daily traffic volume (DTV) is fed in the presented location model in a way that the higher traffic volumes on a road increase the coverage priority and conversely the lower traffics decrease it. However, this increase and decrease are not constant values but depend on assigned weight for this criterion. In order to consider this criterion and its weight in location model, the values of daily traffic volume are categorized in 10 levels, whereas the level 1 indicates to the roads with least traffic volume and the level 10 to the roads with highest traffic volume. The weights of this criterion could vary from “no weight” (the traffic volume criterion is not considered at all) to “very important” (which cause an extreme differences for different traffic volumes). The levels of daily traffic volume and the assigned weight for this criterion will determine the coverage priority each road segment using a linear function as below:

$$\mathrm{Priority_i} = \quad \mathrm{L}_{DTV} + \frac{\mathrm{U}_{DTV} - \mathrm{L}_{DTV}}{DTV_{\mathrm{Max}} - \mathrm{DTV_{Min}}} (DTV_{\mathrm{i}} - DTV_{\mathrm{Min}}) \tag{1}$$

$\mathrm{Priority_i}$: Calculated coverage priority for the road segment i
L_{DTV}: Lower limit corresponding to the assigned weight for DTV
U_{DTV}: Upper limit corresponding to the assigned weight for DTV
DTV_{i}: Level of daily traffic volume on road segment i (1, 2, … , 10)
$\mathrm{DTV_{Min}}$: Minimum level of daily traffic volume ($\mathrm{DTV_{Min}} = 1$)
$\mathrm{DTV_{Max}}$: Maximum level of daily traffic volume ($\mathrm{DTV_{Min}} = 10$)

Table 3
Lower and upper limits of the formula (1) according to the assigned weight for the criterion

	No weight	Very low	Low	Medium	High	Very high
Lower limit	0.5	0.4	0.3	0.2	0.1	0
Upper limit	0.5	0.6	0.7	0.8	0.9	1

The formula (1) calculates the priority of each road segment considering daily traffic volume and the assigned weight, which varies between lower and upper limits. If the assigned weight is “no weight” then the priority of all roads regardless of the level of daily traffic volume will be the same and equals to 0.5. The weight “very high” will cause the extreme differences of the calculated priority in a way that the lowest DTV level results in priority = 0 and highest DTV level results in priority=1.

3.1.2. Foreign Daily Traffic Volume

Depending on goals of the research, planners/decision-makers might be interested to cover the demand for FCSs on those highways which are important for international traffic. In this case the assumption is that the more foreign daily traffic volume (FDTV) on a road, the coverage priority of this road is higher (depending on the weight of this criterion). The values of FDTV is categorized in eight levels (FDTV= 1, 2, …, 8) in which the level 1 indicates to a road segment with the least foreign traffic on it and level 8 indicates to highest foreign traffic. Same as previous section, in this section also a linear function is utilized for considering the weight of foreign traffic for calculating the coverage priority of a road.

$$\mathrm{Priority_i} = \quad \left[\mathrm{L_{FDTV}} + \frac{\mathrm{U_{FDTV}} - \mathrm{L_{FDTV}}}{\mathrm{FDTV_{Max}} - \mathrm{FDTV_{Min}}} (\mathrm{FDTV_i} - \mathrm{FDTV_{Min}})\right] \tag{2}$$

$\mathrm{L_{FDTV}}$: Lower limit corresponding to the assigned weight for FDTV
$\mathrm{U_{FDTV}}$: Upper limit corresponding to the assigned weight for FDTV
$\mathrm{FDTV_i}$: Level of foreign daily traffic volume on road segment i (1, 2, …, 8)
$\mathrm{FDTV_{Min}}$: Minimum level of foreign daily traffic volume ($\mathrm{FDTV_{Min}} = 1$)
$\mathrm{FDTV_{Max}}$: Maximum level of foreign daily traffic volume ($\mathrm{FDTV_{Min}} = 8$)

The assigned weight for the criterion FDTV determines the values of lower and upper limits ($\mathrm{L_{FDTV}}$ and $\mathrm{U_{FDTV}}$) according to the Table 3.

3.1.3. Accessibility for federal highway

Generally, the highways are classified according to their capacity and function. In Germany, the road type “autobahn” with largest capacity and highest traffic speed, is the most important road category for long-distance trips. The second major through-roads are labeled as federal highway (Bundesstraße in German), which have a lower traffic capacity in compare to autobahns, however they are also expected to carry a large volume of inter-city traffic. The federal highway network is more important for the regions, those accessibility to the autobahn is difficult because the inter-city trips of residents in these regions relay mainly on federal highways. Focusing too much on only efficiency criteria such as traffic volume or foreign traffic volume will result to cover only the demand on autobahns (with normally higher traffic volume on them) and the federal highways will be ignored, which could result in inequity issues for the residents of difficult accessible regions. On this account, the decision-makers could be interested in covering the demand for FCSs not only based on efficiency criteria but also with consideration of equity goals by providing the FCSs for the regions which are located relatively far from the autobahn network, In order to consider this criterion in the presented location model, the autobahn accessibility (AAC) of each federal highway is calculated and categorized in 5 classes. The class 1 indicate to those federal highways, which could access an autobahn within 15 minutes and proceeding with 15-minutes steps, the class 5 refers to those, for them the accessibility of an autobahn is more than 60 minutes. A higher coverage priority will be assigned to the federal highways which are far from Autobahn network but those which are in close vicinity of autobahns will be regarded with less priority (depending on weight of this criterion). Calculation of coverage priority of federal highways considering the autobahn accessibility is as below:

$$\text{Priority}_i = \left[\text{L}_{\text{AAC}} + \frac{\text{U}_{\text{AAC}} - \text{L}_{\text{AAC}}}{\text{AAC}_{\text{Max}} - \text{AAC}_{\text{Min}}}(\text{AAC}_i - \text{AAC}_{\text{Min}})\right] \quad (3)$$

L_{AAC}: Lower limit corresponding to the assigned weight for AAC
U_{AAC}: Upper limit corresponding to the assigned weight for AAC
AAC_i: Level of foreign daily traffic volume on road segment i (1, 2, … , 5)
AAC_{Min}: Minimum level of foreign daily traffic volume ($\text{AAC}_{\text{Min}} = 1$)
AAC_{Max}: Maximum level of foreign daily traffic volume ($\text{AAC}_{\text{Max}} = 5$)

The assigned weight for the criterion AAC determines the values of lower and upper limits according to the Table 3. Since the autobahn accessibility is relevant only for secondary roads (the accessibility of an autobahn to autobahn network makes no sense), the average value of lower- and upper limit (0.5) will be added to all priorities of autobahns, so that the priorities of autobahns and secondary roads remains comparable with each other.

3.1.4. Coverage priority: Combination of criteria

Considering more than one creation for determining the coverage priority, the relevant components (formulas 1, 2, 3) will be summed together e.g. considering all three criteria, the following formula will be utilized for determining the coverage priority of federal highway segments:

$$\text{Priority}_i = \left[\text{L}_{\text{DTV}} + \frac{\text{U}_{\text{DTV}} - \text{L}_{\text{DTV}}}{\text{DTV}_{\text{Max}} - \text{DTV}_{\text{Min}}}(\text{DTV}_i - \text{DTV}_{\text{Min}})\right] + \left[\text{L}_{\text{FDTV}} + \frac{\text{U}_{\text{FDTV}} - \text{L}_{\text{FDTV}}}{\text{FDTV}_{\text{Max}} - \text{FDTV}_{\text{Min}}}(\text{FDTV}_i - \text{FDTV}_{\text{Min}})\right] + \left[\text{L}_{\text{AAC}} + \frac{\text{U}_{\text{AAC}} - \text{L}_{\text{AAC}}}{\text{AAC}_{\text{Max}} - \text{AAC}_{\text{Min}}}(\text{AAC}_i - \text{AAC}_{\text{Min}})\right] \quad (4)$$

And coverage priority of autobahn segments will be calculated according to the formula 5.

$$\text{Priority}_i = \left[\text{L}_{\text{DTV}} + \frac{\text{U}_{\text{DTV}} - \text{L}_{\text{DTV}}}{\text{DTV}_{\text{Max}} - \text{DTV}_{\text{Min}}}(\text{DTV}_i - \text{DTV}_{\text{Min}})\right] + \left[\text{L}_{\text{FDTV}} + \frac{\text{U}_{\text{FDTV}} - \text{L}_{\text{FDTV}}}{\text{FDTV}_{\text{Max}} - \text{FDTV}_{\text{Min}}}(\text{FDTV}_i - \text{FDTV}_{\text{Min}})\right] + 0.5 \quad (5)$$

3.1.4. Example for calculation

The priority of each road segment has been calculated considering the following weights for different criteria and the attribute table of highway network shapefile is depicted in the Fig. ***6***.

- Daily Traffic Volume: High
- Foreign Daily Traffic Volume: Very high
- Accessibility for secondary highways: Low

3.2. Effect of existing FCSs

This section analyses the effect of already installed charging infrastructures on covering the demand on the highways because it could be possible that despite a high priority of a road segment, the demand is already satisfied. In order to investigate the effect of existing FCSs in the location model, some technical properties of FCSs and EVs as well as traveler's behavior in term of their detour acceptance should be analyzed which are described in the following sub-chapters.

3.2.1. Type and Efficiency of FCSs

As it is described in second chapter, two key technical characteristics of FCSs are their plug-in system and charging efficiency. The presented location model differentiates between FCSs in terms of these two characteristics (see **Fig. 3**) because different types of plug-in systems are not compatible with all EVs and also the charging efficiency determines the charging time of battery. In order to simplify the calculations in location model, the charging efficiency of FCSs are aggregated into two groups of 50 kW (22 kW up to 50 kW) and 50 + kW (50 kW and more).

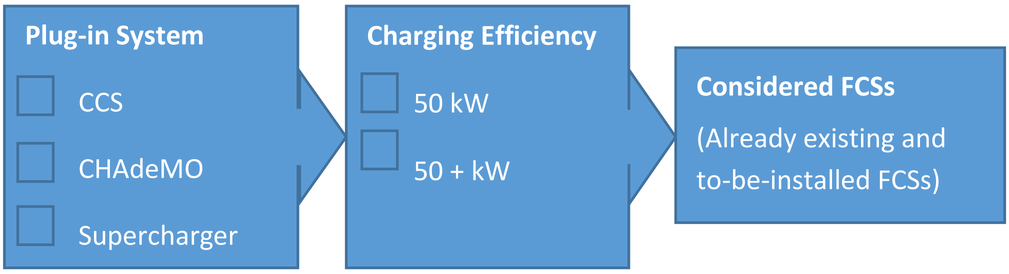


Fig. 3.
Plug-in system and charging efficiency of to-be-installed FCSs

As it is mentioned, the most installed FCSs in practice provide the charging power of 50 kW and more (the 50+ kW group by above grouping), which are able to charge a 20 kWh battery to its 80 percent of capacity within only 15-30 minutes. Considering the significant shorter charging time by 50 + kW FCSs in compare with 50 kW, as well as the use-case of FCSs on the highway network, in which the users aim to charge their battery as quick as possible and proceed their trip for next stage, the regarded FCSs in this paper are 50 + kW FCSs, which are significantly faster than the other group and increases the flexibility of travelers considerably.

3.2.2. Detour to FCSs

The next step is to identify and determine those roads which are affected by the FCSs. In order to do that, we look to the traveler's behavior in term of their detour acceptance. The assumption is the better accessible charging stations located directly to the road are, the easier and more comfortable is its utilization for travelers and by getting far from the road, the attractiveness of FCSs decrease because of larger imposed detour. The FCSs which are located beyond maximum acceptable detour by travelers are not attractive anymore for covering the demand on highways. Here it is necessary to mention that the analyzing the travelers' detour behavior requires a comprehensive user study which is not the topic of this paper. However, a simplified approach with reasonable assumptions has been employed in order to model the travelers' detour behavior, which is depicted **Error! Reference source not found.**. This approach is implemented using network analyses of the ArcGIS software whreas the first class indicates to roads with maximum 2 km detour, the second class indicates the accessible roads with 2-5 km detour **Fig. *1***and the last class specifies those roads from them the FCS is reachable within 5-10 km detour. In the specific example of the Autobahn A96 is located directly to the FCS (passing through the first detour class) and the travelers can utilize it conveniently, while federal highway B17 is reachable with 5-10 km detour which is the third detour class.

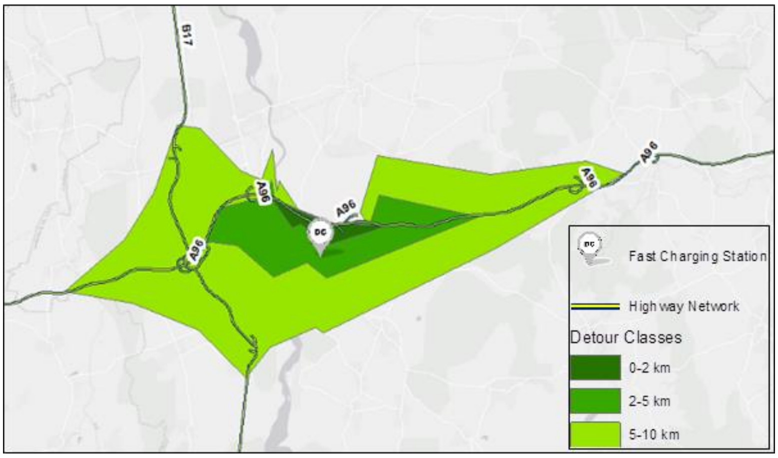


Fig. 4.
Modelling the detour acceptance behaviour of travellers and creating the detour classes using the network analyses in ArcGIS software

3.2.3. Covering the demand on highways

After defining the to-be-considered FCSs in term of plug-in system and charging efficiency as well as identifying the effected roads in different detour classes, it will be analyzed how far along the effected roads the demand will be covered. At this point the range of EVs plays the key role which is described in section 0. In order to setup a comprehensive network of FCSs which supports all EVs with different ranges, the minimum range of 104 km in Table 2 has been utilized. This range is considered as maximum traveled distance until the battery of EV is empty which we call it here as "available range". However, we do not expect that the travelers will make use of all energy of battery till it is depleted. We assume that, before the battery is empty, the travelers search for a charging station in order to avoid the possible staying on the road due to empty battery. A research conducted by Franke (2014) shows that the travelers consider 20-25 percent of the available range of EVs for searching a charging station. After subtracting 25% of available range as buffer for finding a FCSs, we call the remaining range as "comfortable range", which is equal to 78 km. The following scenarios for covering the demand on roads based on the calculated ranges is depicted as below:

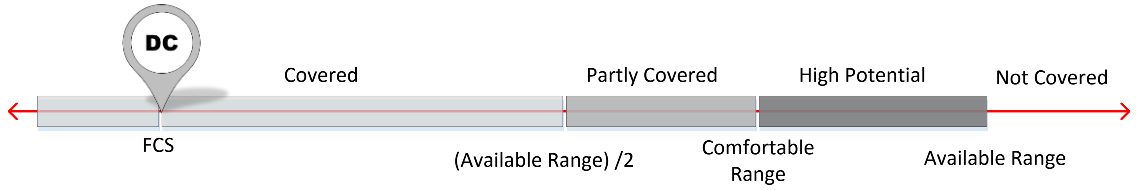


Fig. 5.
Coverage status of highways based on different scenarios of user-charging behaviour and range of EVs

Considering the Fig. ***5***, travelers can depart from depicted FCS until half of available range of EV and come back without intermediate charging (depicted in light grey) which is labelled as "covered" because installing a FCS in this area is not necessary. The dark grey colored road, which is labelled as "high potential" segment is an optimal area for installing a FCSs because, it is the area in which the traveler is searching for a FCS to refuel the battery. Installation of a FCS on the road segments farther than dark grey depicted area is not interested anymore because of range limitation. If installing a charging stations is not possible in the "High Potential" depicted road segment (due to technical issues, installation cos, etc.), then the middle grey colored area is in second priority, which is farther than half of available range but the traveler is still in the comfortable range. The mentioned approach is performed with consideration of FCSs with CCS plug-in system and minimum charging efficiency of 50 kW as well as the three detour classes mentioned in previous section. In so doing, the attribute table of highway shapefile will contain three columns corresponding to the three detour classes and the content of them is the coverage status of each road segment (see the Fig. ***6***).
If a road segment is influenced by more than one FCS, which is located in a same detour class, e.g. a road segment is considered as "covered" regarding a FCS and at the same time it is considered as "high potential" regarding another FCS, then only one coverage status should be written in the corresponding column of attribute table, which is determined according to the Table 4. For example in above mentioned case, only the status "covered" will be assigned to the road segment.

Table 4
Determining the coverage status in case of several coverage statuses in a same detour class

Several coverage statuses in a same detour class	Coverage status in the attribute table
Covered, partly covered, high potential	Covered
Partly covered, high potential	Partly covered

3.3. Calculating the potential of each road segment

This section aims to calculate the potential of each road segment for installing a FCS based on coverage priority and effect of existing FCSs for satisfying the demand on highway. The coverage priority of each road segment has already been quantified in the section 0 and now the effect of existing FCSs, which is reflected as coverage statuses of a road segment in different detour classes (see the section 0), will be quantified and utilized as a weight in order to calculate the potential of road segments. A better contribution of a road segment for setting up a FCSs network in combination with existing FCSs results to higher weights for this road segment. In addition to coverage status of a road segment, the travelers' detour acceptance behavior also should be regarded for determining the weights, which are described in following assumptions:

- If a road segment is located in "covered" area of a FCS in detour class 1 (light grey segment in Fig. ***5***), it means that the demand for FCS is satisfied with a very good service quality and consequently the potential of this road section will be very low (almost zero). However, if the charging station is located in second or third detour classes, then the travelers need to take a longer detour to reach it therefore, installing an additional FCS in close vicinity of highway (which is accessible within the detour class 1) increases the travelers' comfort. Therefore, if a road segment is covered with second or third detour classes, the potential of this road segment, due to its potential to increase the user's comfort, will be higher than a road segment covered in first detour class.
- If a road segment is located in "high potential" area (dark grey colored segment in Fig. ***5***), then installation of a new charging stations could optimally contribute for setting up a FCSs network and covering the demand on highways. For this reason, the highest weight will be assigned to this road segment. However, the

assigned weight varies according to the detour classes in a way that the higher weight will be assigned to “high potential” segment in detour class 1 and the weights decreases for farther located FCSs.

- The “partly covered” road segments (middle grey area in Fig. ***5***) are considered as second priority area, in case the installation in “high potential” areas is not possible due to technical or financial issues. The weights in compare with “high potential” areas are lower but they are higher than covered areas. The corresponding weights will be determined again in accordance with detour classes.
- The “not covered” road segments are not influenced by existing FCSs therefore, the assigned weights to them are assumed to be higher than “covered” areas and lower than “partly covered” and “high potential” road segments. Since they are not influenced by existing charging stations, the detour classes is meaningless in this situation.

Considering the above mentioned assumptions and the fact that their order and interrelationship are important, the number of possible combinations is 4*4*4 = 64. It should be noted that, there is no single correct way for determining the value of weights but the important point is to respect the mentioned assumptions, which make the assigned weights comparable to each. We assigned appropriate weights for each combination by consideration of the above mentioned assumptions as well as calibration of them in several pre-implementations of the location model. The calculated values of coverage priority and the assigned weights for each road segment are now determined and the potential of each road segment will be calculated by multiplying these two values (see the Fig. ***6***).

Tabelle

Highway Network

FID	Shape *	Heighway_Name	DTV	FDTV	ACC	Priority	Detour_Class_1	Detour_Class_2	Detour_Class_3	Weight	Potential
0	Polylinie	A98	1	8	0	1,4	Not Covered	Covered	Covered	0,5	0,7
1	Polylinie	A98	1	8	0	1,4	Not Covered	Covered	Covered	0,5	0,7
2	Polylinie	A98	1	2	0	0,714286	Not Covered	Covered	Covered	0,5	0,357143
3	Polylinie	A98	1	2	0	0,714286	Not Covered	Covered	Covered	0,5	0,357143
4	Polylinie	A98	1	3	0	0,828571	Not Covered	Covered	Covered	0,5	0,414286
5	Polylinie	A98	1	3	0	0,828571	Not Covered	Covered	Covered	0,5	0,414286
6	Polylinie	A861	1	2	0	0,714286	Not Covered	Covered	Covered	0,5	0,357143
7	Polylinie	A98	1	8	0	1,4	Not Covered	Covered	Covered	0,5	0,7
8	Polylinie	A98	1	8	0	1,4	Not Covered	Covered	Covered	0,5	0,7
9	Polylinie	A98	1	8	0	1,4	Not Covered	Covered	Covered	0,5	0,7
10	Polylinie	A98	1	2	0	0,714286	Not Covered	Covered	Covered	0,5	0,357143
11	Polylinie	A98	1	8	0	1,4	Covered	Partly Covered	Covered	0,5	0,7
12	Polylinie	A98	1	8	0	1,4	Covered	Partly Covered	Covered	0,5	0,7
13	Polylinie	A861	1	2	0	0,714286	Covered	Partly Covered	Covered	0,5	0,357143
14	Polylinie	A5	1	8	0	1,4	High Potential	Partly Covered	Partly Covered	1	1,4
15	Polylinie	A98	1	8	0	1,4	High Potential	Partly Covered	Partly Covered	0,5	0,7
16	Polylinie	A98	1	3	0	0,828571	High Potential	Partly Covered	Partly Covered	0,5	0,414286
17	Polylinie	A98	1	3	0	0,828571	High Potential	Partly Covered	Partly Covered	0,5	0,414286
18	Polylinie	A98	1	3	0	0,828571	High Potential	Partly Covered	Partly Covered	0,5	0,414286
19	Polylinie	A98	1	8	0	1,4	High Potential	Partly Covered	Partly Covered	0,5	0,7
20	Polylinie	A98	1	8	0	1,4	Not Covered	Not Covered	Not Covered	0,5	0,7
21	Polylinie	A98	1	8	0	1,4	Not Covered	Not Covered	Not Covered	0,5	0,7
22	Polylinie	A98	1	8	0	1,4	Not Covered	Not Covered	Not Covered	0,5	0,7
23	Polylinie	A98	1	2	0	0,714286	Not Covered	Not Covered	Not Covered	0,5	0,357143
24	Polylinie	A98	1	2	0	0,714286	Not Covered	Not Covered	Not Covered	0,5	0,357143
25	Polylinie	A98	1	2	0	0,714286	Not Covered	Not Covered	Not Covered	0,5	0,357143
26	Polylinie	A861	1	2	0	0,714286	Not Covered	Not Covered	Not Covered	0,5	0,357143
27	Polylinie	A5	1	8	0	1,4	Partly Covered	High Potential	Not Coveredl	1	1,4
28	Polylinie	A5	1	8	0	1,4	Partly Covered	High Potential	Not Coveredl	1	1,4
29	Polylinie	A5	1	8	0	1,4	Partly Covered	High Potential	Not Coveredl	1	1,4

18 (0 aus 16269 Ausgewählte)

Highway Network

Fig. 6.
Attribute table of highway shapefile after calculation of the potential of each road segment

3.4. Selecting the optimal locations

The first optimal location for FCSs on highways is determined based on highest calculated potential of road segments. The selected location, which is assumed as middle point of the road segment with highest calculated potential, is considered as a new charging station and its effect on covering the demand on highways and subsequently on potential of road segments will be investigated. It should be noted that the to-be-installed charging station is located in detour class 1 of the road segment with highest potential, because it is supposed that the new station will be installed directly to the highway due to travelers comfort. By doing this, the status of those road segments, which are affected by the new charging stations and consequently the assigned weights of them should be updated. The potential of road segments also will be calculated again according to the new assigned weights and the next optimal location will be selected according to the updated potentials. In each iteration for selecting the next optimal location, the conditions for ending the selectin loop should be checked otherwise the selection loop will continue until all road segments will be selected. The terminating condition could be defined based on research goals and decision maker’s opinion for example ending the iteration after selection of specific number of optimal locations or covering a specific percentage of highway network with specific detour class.

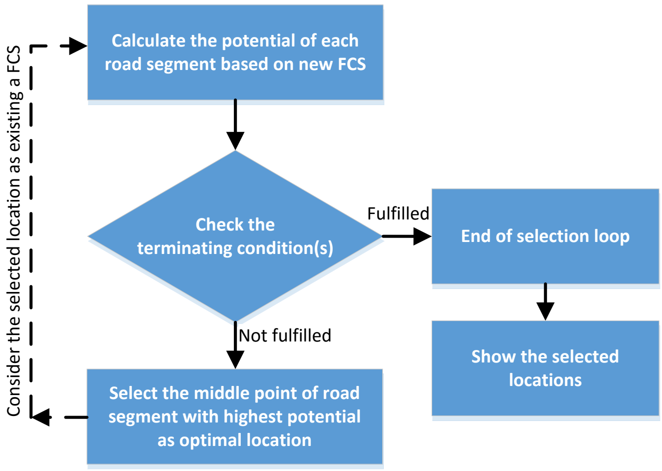


Fig. 7.
Iteration process of location model in order to select the optimal locations

4. Results

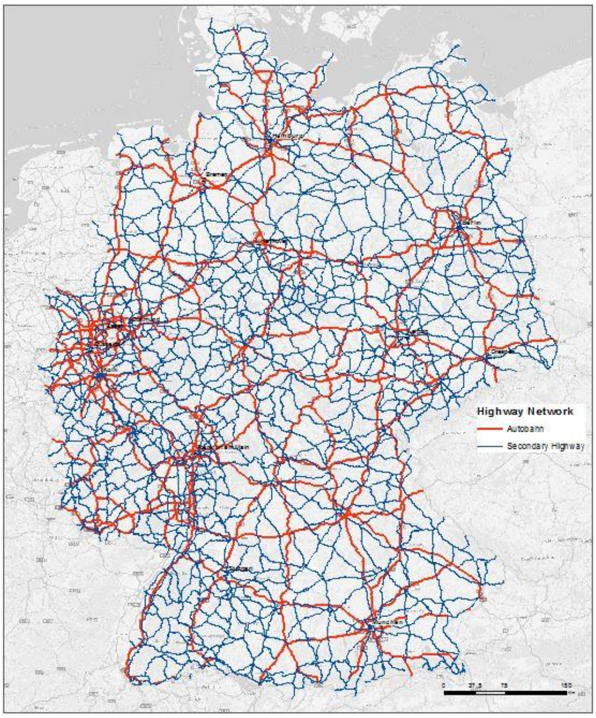
In order to implement the introduced location model in real case, the highway network of Germany with nearly 13,000 km autobahn and 38,000 km secondary roads (Bundesstraße in German), which is one of the most dense highway networks in Europe, has been selected. The required input data for the location model in this area has been collected from different sources which will be introduced in the relevant sections. The gathered data are prepared and edited in form of georeferenced shapefile layers, so that they could be combined and spatially analyzed in ArcGIS software. According to the first step of the location model methodology the coverage priority of road segments has be determined. It should be noted that there is no single correct way to determine the coverage priority and it depends on goals of projects from decision makers' point of view and assigned weights to different criteria. This research utilized following weights shown in Table 5, which focus rather on efficiency of to-be-installed FCSs and the optimal locations will be determined based on this scenario.

Table 5
Source and weight of network data and criteria for determining the coverage priority of road segments

Data/Criteria	Source	Weight
Highway network shapefile data	HERE Maps (Release date: Q3 of 2016)	--
Daily Traffic Volume (DTV)	Automatic counting System, BASt (2015) [1]	Very high
Foreign Daily Traffic Volume (FDTV)	Bast (release date: 2013)	High
Autobahn Accessibility (AAC)	BBSR (release date: 2015) [2]	low

The prioritized road segments were categorized in five different levels from "very low" to "very high" priority and illustrated on the right side of Fig. **8**.

[1] Retrieved at 02.08.2016 from website of Bundesanstalt für Straßenwesen (bast):
http://www.bast.de/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/Aktuell/zaehl_aktuell_node.html
[2] Retrieved at 02.08.2016 from website of Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR):
http://www.bbsr.bund.de/BBSR/DE/Raumbeobachtung/Downloads/HaeufigNachgefragteKarten/ErrBAB.pdf?__blob=publicationFile&v=6



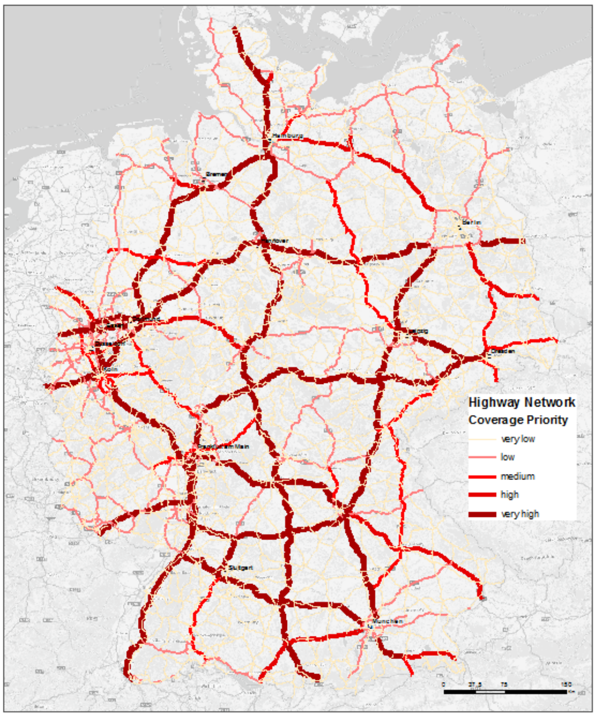


Fig. 8.
Left side: Whole highway network in Germany including autobahns and secondary highways
Right side: Categorisation of highway network based on their coverage priority
Source: Here Maps; Background: Openstreetmap.org

In order to investigate the effect of existing charging infrastructures, first the type of to-be-considered FCSs should be defined. This research considers the FCSs with plug-in system of Combined Charging System (CCS) and minimum charging power of 50 kW. The required input data of existing charging infrastructure have been retrieved from GoingElectric.de website[1] which is converted in shapefile format by means of ArcGIS software. The total number of existing CCS charging stations with minimum 50 kW power is 239. Three detour classes of 2 km, 5 km and 10 km were adopted for reflecting the different comfort levels of users in term of their detour acceptance and in so doing, those roads their demand is influenced by existing FCSs in different detour classes have been identified. By applying the available and comfortable range of 104 km and 74 km, respectively, the location model shows that 71% of autobahns are already covered considering the maximum detour of 10 km, which is shown at the right side of Fig. 9. It should be noted that the road segments with "very low" coverage priority have not been shown in the depicted highway networks of Fig. 9 due to simplification and better visualization. By the way, their potential, which are important for selection of optimal locations, is still calculated in the location model.
After clarifying the coverage status of each road segment in different detour classes and assigning the corresponding weight, the potential of each road segment will be calculated by multiplication of the assigned weights and the calculated coverage priority. The first optimal location will be selected based on the highest calculated potential and then it will be considered as an existing charging station for next selection. The iteration loop for selecting the locations of new charging stations has been executed until one of the following terminating conditions for ending the selection process is fulfilled:

- Selection of maximum 40 new locations for fast charging stations or
- Coverage of minimum 90% of Autobahns with detour class 3.

The first condition represents the limitation in number of to-be-installed charging stations, which refers to possible restrictions in term of available budget and could be interesting condition especially form decision makers' point of views. The second condition is considered due to efficiency of to-be-installed FCSs in the network and it is not set on coverage of 100% of autobahns because in some cases, especially at the close vicinity of borders, where covering a small road segment of highway network could cost an additional FCS and might be not so interesting in term of cost-benefit consideration. On the other hand, the uncovered road segments at the edge of borders could be already covered by FCSs beyond the borders in the neighbor countries, which are not regarded in this research. It should be also mentioned, that the utilized conditions for ending the iteration loop could differ according to the research's goals however, these two conditions were adopted in order to generate a scenario-based result of the developed location model. By running the location model and after the selection of first 20 optimal locations, the covered area of autobahns

[1] Retrieved at 01.07.2016 from website of http://www.goingelectric.de/

increases to 80% (depicted map at the middle of Fig. **9** and by continuing the selection process until 40 optimal locations, the coverage status of autobahns reaches 86% coverage of whole autobahn network. Since the first condition for ending the selection loop is satisfied, the location model stops selecting further locations.

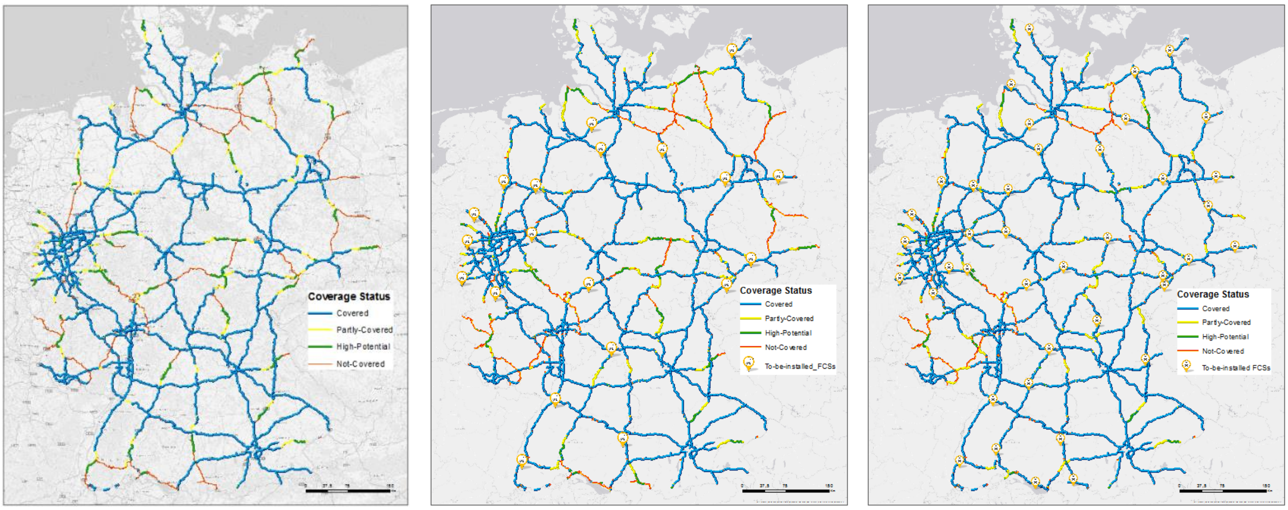


Fig. 9.
Left side: coverage status of highway network in Germany considering existing charging stations
Middle: Optimal location of first 20 to-be-installed FCSs and their effect on coverage of highway network
Right side: Optimal location of first 20 to-be-installed FCSs and their effect on coverage of highway network
Source: Here Maps, Goingelectric.de; Background: Openstreetmap.org

5. Conclusion

As any other motorized transport mode, EVs also need an appropriate refueling infrastructure for their energy source. Regarding the current limited range of EVs, the users expect a fast, reliable and easy accessible charging infrastructure on the main roads for their intercity and long distance trips. The proposed model in this paper aims to develop an efficient and transparent model, in order to cover the growing demand for FCSs of current EV users on the major roads which is also one step forward to increase the acceptance of electro mobility as a very important component of sustainable transportation. The proposed location model in this paper tries to determine the optimal location of FCSs on the major highway network based on different criteria from decision-maker's and end-user's point of view. By means of prioritizing the highway network via assigning different weights for coverage priority criteria, the decision makers are able to determine the optimal location of new FCSs in accordance with goals of project. The prioritizing criteria include two efficiency criteria of Daily Traffic Volume (DTV) and Foreign Daily Traffic Volume (FDTV) as well as an equity criterion of Autobahn ACcessibility for federal highway (AAC), which enables the decision makers to combine them with different weights in order to calculate their scenario-based results. There is no interrelationship between the utilized criteria however, they could be insufficient and other relevant criteria could be added to these list. In addition, the three different detour classes in the location model consider the user's behavior in term of detour acceptance and represent the comfort levels of users in the location model. The utilized values for detour classes in this paper are estimated based on the distance of rest areas on the highway however, a comprehensive user-study is required in order to determine them. Moreover, the user's charging behavior is simulated in the location model by considering the range of an EV and range anxiety of users, which is reflected in different coverage statuses. Although utilizing the range of EVs in real world condition and considering the 80% as state of charge of battery by departure however, a hidden assumption in location model is that the users have all information about location of next FCSs and they won't miss a charging station mistakenly which is an ideal assumption and the validity of these assumption should be also proved.
Considering above mentioned assumptions a scenario-based result has been calculated, which shows a reasonable and acceptable result. A more precise look into the determined locations shows that a considerable number of selected locations are at the close vicinity of borders. Beside high assigned weight of foreign traffics, which could be a reason for these selections, the accurateness and validity of these selections should be proved by considering the stations in the neighbor countries, because existing charging stations right beyond the border on the same road could satisfy the demand on the road so that an additional FCSs is not required anymore. Finally, it is worth mentioning that although the pillar of this research is dedicated to find the optimal location of fast charging infrastructure however, the proposed model is developed in a way that is adaptable for other refueling infrastructures such as Hydrogen or CNG (Compressed Natural Gas) stations.

Acknowledgements

We are grateful to Mrs. Nasim M.Nejad Fard and Mr. Yordan Monolov for their assistance with implementation of the model, especially by their outstanding programming skills, which improved the manuscript significantly.

References

Bayram, I.S.; Michailidis, G.; Devetsikiotis, M.; Granelli, F. 2013. Electric power allocation in a network of fast charging stations. Selected Areas in Communications, *IEEE Journal*, 31(7): 1235-1246

Bundesanstalt für Straßenwesen (Bast), 2013. Zählungen des ausländischen Kraftfahrzeugverkehrs, Darstellung und Aufbereitung der Ergebnisse der AVZ 2008 im Bundesinformationssystem Straße, Bericht zum AP F1100.6607039, Bergisch Gladbach

Channegowda, J.; Pathipati, V.K.; Williamson, S.S. 2015. Comprehensive review and comparison of DC fast charging converter topologies: Improving electric vehicle plug-to-wheels efficiency. In 2015 IEEE 24th International Symposium on Industrial Electronics (ISIE), 263-268. IEEE.

Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure (2014) Official Journal of the European Union L307: 1-20.

Egbue, O.; Long, S. 2012. Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions, *Energy policy*, 48: 717-729.

Franke, T. 2014. Nachhaltige Mobilität mit begrenzten Ressourcen: Erleben und Verhalten im Umgang mit der Reichweite von Elektrofahrzeugen. Dissertation. Betreut von Josef F. Krems. Technischen Universität Chemnitz Chemnitz.

Frenzel, I.; Jarass, J.; Trommer, S.; Lenz, B. 2015. Erstnutzer von Elektrofahrzeugen in Deutschland. Nutzerprofile, Anschaffung, Fahrzeugnutzung, DLR-Forschungsbericht, Online verfügbar unter http://elib.dlr.de/96491, zuletzt geprüft 15.08.2016.

Li, S.; Huang, Y.; Mason, S.J. 2016. A multi-period optimization model for the deployment of public electric vehicle charging stations on network. Transportation Research Part C: Emerging Technologies, 65: 128-143.

Mohsenzadeh, A.; Pang, C.; Pazouki, S.; Haghifam, M. 2015. Optimal siting and sizing of electric vehicle public charging stations considering smart distribution network reliability. In North American Power Symposium (NAPS), 1-6. IEEE.

Nicholas, M.A.; Tal, G.; Davies, J.; Woodjack, J. 2012. DC Fast as the Only Public Charging Option? Scenario Testing from GPS-Tracked Vehicles. In Transportation Research Board 91st Annual Meeting (No. 12-2997).

Rezvani, Z.; Jansson, J.; Bodin, J. 2015. Advances in consumer electric vehicle adoption research: A review and research agenda, *Transportation research part D: transport and environment*, 34: 122-136.

Sathaye, N.; Kelley, S. 2013. An approach for the optimal planning of electric vehicle infrastructure for highway corridors, *Transportation Research Part E: Logistics and Transportation Review*, 59: 15-33.

Schroeder, A.; Traber, T. 2012. The economics of fast charging infrastructure for electric vehicles, *Energy Policy*, 43: 136-144.

Smart, J.; Powell, W.; Schey, S. Extended Range Electric Vehicle Driving and Charging Behavior Observed Early in the EV Project, SAE Technical Paper 2013-01-1441, 2013, doi:10.4271/2013-01-1441.

Wang, G.; Xu, Z.; Wen, F.; Wong, K.P. 2013. Traffic-constrained multiobjective planning of electric-vehicle charging stations, *Power Delivery, IEEE Transactions on*, 28(4): 2363-2372.

Wirges, J.; Linder, S.; Kessler, A. 2012. Modelling the development of a regional charging infrastructure for electric vehicles in time and space, *European Journal of Transport and Infrastructure Research*, 12(12): 391-416.

Zhang, L.; Shaffer, B.; Brown, T.; Samuelsen, G.S. 2015. The optimization of DC fast charging deployment in California, *Applied Energy*, 157: 111-122.

Zhu, Z.H.; Gao, Z.Y.; Zheng, J.F.; Du, H.M. 2016. Charging station location problem of plug-in electric vehicles, *Journal of Transport Geography*, 52: 11-22.

ANALYSIS OF RAILWAY INFRASTRUCTURE CHARGES FEES ON THE LOCAL PASSENGERS LINES IN CROATIA

Borna Abramović[1], Jasmina Pašagić Škrinjar[2], Denis Šipuš[3]
[1,2,3] University of Zagreb, Faculty of Transport and Traffic Sciences, Vukelićeva 4, HR – 10000 Zagreb, Croatia

Abstract: According to the document by the European Commission entitled White Paper, railway transport is the road-map to a Single European Transport Area – towards a competitive and resource efficient transport system, and one of the pillars of future development of transport and traffic in Europe. The document also emphasizes the importance of mobility in passengers transport and highlights the significance of an integrated passenger transport system not only in urban but also rural areas. Railway lines in rural areas are very often referred to as local railway lines. The backbone of an integrated passenger transport system is the railway, which offers some interesting advantages: (1) speed, (2) capacity, and (3) comfort. Except for some passengers services in Croatia, the railway system across the European Union is fully liberalized. In that kind of railway system there are two pillars: (1) infrastructure managers and (2) railway undertakings. Railway undertakings must pay the infrastructure managers charges fees for the train running. Pursuant to the EU directive 2012/34 there are four services that can be provided by infrastructure manager: (1) minimum access package, (2) track access to services facilities, (3) additional services, and (4) ancillary services. On other hand, railway undertaking must at least pay for the minimum access package, while other services depend on the strategy from railway undertakings. The last few years in Croatia have seen a very dynamic change of the fees paid by the railway undertaking to the infrastructure manager in Croatia. In our research we investigate how the principals and amount of fees influence train running service on local passenger lines. The fee amount is the direct expenditure for railway undertaking and directly determines the ultimate ticket fare. We therefore compare the revenue with the cost of minimum access package to establish appropriate sustainable connection both for railway undertaking and for infrastructure manager.

Keywords: railway infrastructure, charging system, integrated passenger transport system, Croatia.

1. Introduction

In 1991 the European Union issued the 91/440/EC directive on the common development of railway transport, thus setting the framework for liberalization of services in railway traffic. The most important step therein was to enable all the interested parties to use the railway infrastructure. For that to be viable two important aspects needed to be considered: (1) technology of operations and (2) safety. The technology of operation understands new rules of traffic organization in instances of several operators. The principles of transparency and neutrality needed to be laid down in the new regulations. Also, an important factor in technology of operations is the model of railway infrastructures fees. Namely, each operator is obliged to pay the infrastructure manager a certain fee due for the service provided on the railway infrastructure. The basic principles for constructing such a model must include: (1) simplicity, (2) transparency, (3) neutrality and (4) cost dependency. The simplicity basically indicates that there are no additional hidden or ambiguous calculation terms in the practical application of the model. Also, the term refers to the clear and logical workings of the calculation. The transparency means that regardless of the operator, the fees will be consistent and fair, so the operators will be able to check among themselves the amount each has paid for the services. Neutrality is the infrastructure manager having an equal approach and attitude towards every operator. Since the fee model involves charging for various services, the model itself must be based on the actual generated costs for a specific service. This way directly covers the principles of simplicity, transparency and neutrality.

The last few years has seen a new wave of changes in the legal basis of the EU in terms of railway traffic, the so-called fourth railway package. It contains the 2012/34/EU directive which is defined as a directive recasting the establishment of a single European Railway Area and Regulation 2015/909 on the modalities for the calculation of the cost that is directly incurred as the result of operating the train service. Naturally, the main reason for the fourth railway package was the lack of success of the previous model shifts. In fact, there was no significant model shift from road to railway transport, but rather a freeze of the model split in favor of the roadway traffic. The directive states two basic principles of charge fees for the railway infrastructure, while the Regulation strictly defines the way of determining the charges and the charges of the railway infrastructure usage.

The underlying document that regulates the relationship between the infrastructure manager and operator is called Network Statement. It regulates the manner and procedure of drawing up contracts about the access to the railway infrastructure, the technical and technological parameters, and the technology of charging fees for the use of the railway. There is only one railway infrastructure manager in Croatia - HŽ Infrastruktura Ltd., which publishes the Network statement for the railway lines in the country, in Croatian and English. The Network statement is available on web page of infrastructure manager.

In the Republic of Croatia, the railway lines are divided into: (1) international, (2) regional and (3) local. Based on the railway length, the international lines make up 60.5 %, the regional 21.6 % and the local 17.9%. The local railways are in various technical conditions, which requires establishing several categories of the railway conditions: (1) closed to traffic, (2) open to traffic, (3) open to freight traffic, and (4) bus replacement service. The last decade has been marked by a reduction of the number of trains operating on local lines, particularly on Saturdays and Sundays, or replacing the train services with buses. It is therefore possible to investigate the relation between the railway infrastructure charges

[1] Corresponding author: borna.abramovic@fpz.hr

and the total income of sold tickets. This way we can determine the infrastructure cost share in the total income of sold tickets. This approach can also set up the basis for optimizing expenditure entries in the operation of railway transport on local lines.

2. Analysis of Local Railway Lines in Croatia

The railway network Croatia is comprised of 2,722 km, 2,468 km (90.7%) single-track and 254 km double-track lines (9.3 %). There are 980 km of electrified railway lines, 977 of which use the 25 kV/50 Hz electrification system, and 3 km use 3 kV ((Šapjane – Ilirska Bistrica (SI)). The railway infrastructure of the Republic of Croatia is connected to the railway infrastructure Slovenia, Hungary, Serbia and Bosnia and Herzegovina. The changes of haul systems are available on two border crossings, with the Republic of Slovenia in train station Šapjane, on section Rijeka - Šapjane - DG - Ilirska Bistrinca and in station Dobova, on section Dobova - DG - Savski Marof - Zagreb GK. The division of the railway lines in the Republic of Croatia has been made pursuant to Decision on Classification of Railways in three categories: (1) international lines, (2) regional lines, and (3) local lines. The total length of the local railway line is 518.5 km comprising 19.1% of the total length of railway lines. All local lines in Croatia are Diesel only operation. Figure 1 shows the railway network in the country and Table 1 provides the list of all local lines. There are 16 local lines altogether, some of which do not provide any kind of services: (1) L102 Savski Marof – Kumrovec – State border – (Imeno), (2) L210 Sisak Caprag – Petrinja and (3) L213 Lupoglav – Raša, and the following lines operate only freight trains: (1) L207 Bizovac – Belišće, (2) L211 Ražine – Šibenik Luka and (3) L212 Rijeka Brajdica – Rijeka. The rest of the local lines operate train services but the following lines use bus replacement services: (1) Daruvar – Pčelić rasputnica (part of L204) and (2) Pleternica – Našice (part of L205). Only 8 local lines (50% local railway lines) have passengers train services. Looking at the number of trains per day, the line L101 Čakovec – Mursko Središće has 5 departures, L209 Vinkovci – Županja 7 departures, lines L103 Karlovac – Ozalj – Kamanje, L201 Varaždin – Ivanec – Golubovec, L206 Pleternica – Požega – Velika, and L208 Vinkovci – Gaboš – Osijek 8, and L202 Hum-Lug rasputnica – Gornja Stubica and L203 Križevci – Bjelovar – Kloštar has 11 departures. Usually, diesel rail cars HZ series 7121 (Plavac) and HZ series 7122 (Sved) are used on local railway lines.

Table 1
Local railway lines in Croatia

Code of track	Railway line name	Length [km]
L101	Čakovec – Mursko Središće – State border – (Lendava)	17.942
L102	Savski Marof – Kumrovec – State border – (Imeno)	38.522
L103	Karlovac – Ozalj – Kamanje – State border – (Metlika)	28.799
L201	Varaždin – Ivanec – Golubovec	34.596
L202	Hum-Lug rasputnica – Gornja Stubica	10.820
L203	Križevci – Bjelovar – Kloštar	62.047
L204	Banova Jaruga – Daruvar – Pčelić rasputnica	95.752
L205	Nova Kapela-Batrina – Pleternica – Našice	60.493
L206	Pleternica – Požega – Velika	24.955
L207	Bizovac – Belišće	12.940
L208	Vinkovci – Gaboš – Osijek	33.770
L209	Vinkovci – Županja	28.073
L210	Sisak Caprag – Petrinja	11.018
L211	Ražine – Šibenik Luka	3.714
L212	Rijeka Brajdica – Rijeka	2.037
L213	Lupoglav – Raša	52.996

Source: Decision on Classification of Railways (Official Gazette, NN 3/14)

3. Legal Basis of Infrastructure Charges Fees in the European Union

The legal basis of the EU railway network is laid out in its four railway packages and is constantly evolving with a framework of directives and regulations. It is important to recognize the difference between a directive and a regulation. A directive is a recommendation that the EU makes regarding the best practice, and parties usually have a two-year period to adhere to such a guideline. However, a regulation is a legally binding instruction to whomever it concerns and must therefore be complied with. Directives are implemented in the local law, but regulations apply directly to the national legal system. Fourth railway packages contain the Directive 2012/34/EU which is defined as a directive recasting the establishment of a single European Railway Area and Regulation 2015/909 on the modalities for the calculation of the cost that is directly incurred as a result of operating the train service.

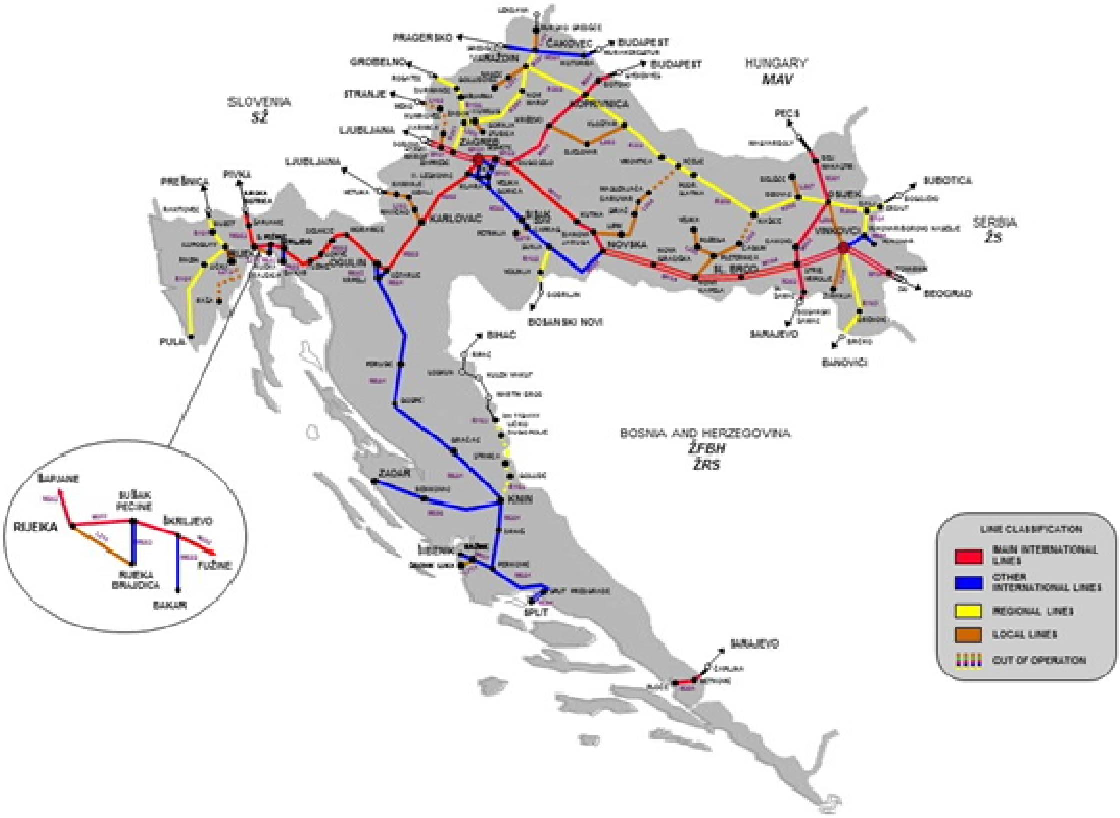


Fig. 1.
Railway classification lines in Croatia
Source: Network Statement, HŽ Infrastructure Ltd (2016)

For operation purposes, the most important document for railway undertakings (RU) is the Network Statement (NS), which is a legal foundation for cooperation between railway infrastructure managers (IM) and railway undertakings. All infrastructure managers of a country must publish a network statement that is available for consideration by all rail operators. It has to be published both in the native language of the country and in English. All operators must have similar structures to allow the ease of access and the liberalization of the European Rail network. Their main contents consist of 6 sections:

1. General Information,
2. Access conditions,
3. Infrastructure,
4. Capacity allocation,
5. Services, and
6. Charges.

Network Statement explains much more clearly how railway undertaking can use railway infrastructure and run the train – service. Pursuant to the Directive there are four different railway services:

1. Minimum access package,
2. Access to services facilities and supply of services,
3. Additional services, and
4. Ancillary services.

All of those services are very clearly and completely explained in the Network Statement. The most important for train running is, of course, the minimum access package. It contains the following services:

- Handling of requests for railway infrastructure capacity,
- The right to utilize capacity which is granted,
- Use of the railway infrastructure, including track points and junctions,
- Train control including signaling, regulation, dispatching and the communication and provision of information on train movement,
- Use of electrical supply equipment for traction current, where available, and
- All other information required to implement or operate the service for which capacity has been granted.

Access to services facilities and supply of services concerns railway undertakings access to service facilities such as access to passenger stations, freight terminals and sidings. In practice, this means any facility on the network that is run or controlled by the infrastructure manager.
Additional services can refer to a number of extra services such as a traction current, control of transport of dangerous goods or assistance in running exceptional consignment trains.
Ancillary services may comprise services such as access to telecommunication networks or ticketing services in passenger services.
The charges section simply focuses on the charging principles in operation in that country, the specific tariffs, any financial penalties and incentives, and billing arrangements. A measure that has been incredibly helpful in this section is the use of EICIS (European Infrastructure Charging System) which provides a single online location where any rail operator can calculate potential infrastructure charges. This is a hugely liberalizing innovation which brings more transparency to a sometimes confusing system.

4. Infrastructure Charges Fees on the Local Passenger Lines in Croatia - A Case Study

For our research we have chosen only local railway lines that run trains: L101 Čakovec – Mursko Središće, L103 Karlovac – Ozalj – Kamanje, L201 Varaždin – Ivanec – Golubovec, L202 Hum-Lug rasputnica – Gornja Stubica, L203 Križevci – Bjelovar – Kloštar, L206 Pleternica – Požega – Velika, L208 Vinkovci – Gaboš – Osijek and L209 Vinkovci – Županja.
According to the official tariff of HŽ Passenger Transport we have determined the fare of a one-way, second class ticket. HŽ Passenger Transport uses the principle of distance for determining the fare, in particular the so-called tariff distance, not the real distance. The tariff distance is on average 5.23 % higher than the real distance. The calculated relationship between the ticket fare and tariff distance is illustrated in Figure 2. The relation should generally be slightly degressive when applying the principle of distance in the calculations, which would indicate that by increasing the distance the fare would drop. Our case leads to the conclusion that there was no digression. Most interestingly, the fare for distances 17, 34, and 71 kilometers remains approximately the same. Observing the obtained results independently shows a digression up to the 25th kilometer, which disappears and reappears after the 28th tariff kilometer. This indicates the existence of two zones of digression. Such a case can be explained by the fact that the fare was formed based on the actual tickets sold, based on the distance, and the zones with a sudden increase in the number of passengers resulted in the increase in ticket fares.

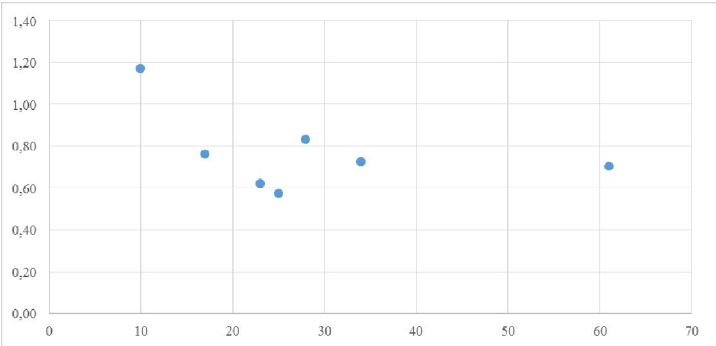


Fig. 2.
Correlation between tariff length and ticket price
Source: Authors

HŽ Infrastruktura is the only infrastructure manager of railway infrastructure in the Republic of Croatia publishing the Network Statement. The charging principles for railway usage charges fees are found in section 6 of the Statement. Our research was limited to calculation of the minimum access package. The formula for determining the minimum access package is listed below:

$$C = (T + d_m + d_n)\cdot\sum(L\cdot l)\cdot C_{vlkm}\cdot K \text{ [HRK]} \quad (1)$$

C – minimum access package charge [HRK]
T – train path equivalent
d_m – additional charge for train mass
d_n – additional charge for the use of tilting technique
L – line parameter
l – train path length [km]
C_{vlkm} – basic price [HRK/trainkm]
K – price correction coefficient

The equivalent of the train route is defined separately for passenger and freight traffic. The former is defined in 5 categories, with trains ranked in one of them. Since only the passenger rank trains operate on the local railway lines, all share the same equivalent of 0.95. Our research did not require calculating additional charges (mass greater than 1500 t and tilting technique). The following data used for the calculation is the line parameter. The railway lines are divided into six categories, which is unrelated to the Decision on Classification of Railways. For instance, the railway line L208 Vinkovci – Gaboš – Osijek belongs to category 3, with parameter 0.9, while other lines belong to category six with parameter 0.3.
The charge calculations use the real distance covered by the train.
The basic cost is defined separately for the passenger and freight transport, the former at 5.99 HRK per train kilometer.
The calculation also uses a price correction coefficient of 0.5 determined by the infrastructure manager with the consent of the Ministry of Maritime Affairs, Transport and Infrastructure.
The calculation is made for each individual railway line, with added VAT of 25%.
After that we were able to determine which type of railway vehicle is used most frequently on a specific local railway line. Railway lines that use the HZ series 7122 (Sved) are L101 Čakovec – Mursko Središće, L103 Karlovac – Ozalj – Kamanje and L209 Vinkovci – Županja. The passenger capacity for HZ series 7122 (Sved) is 64. Lines L201 Varaždin – Ivanec – Golubovec, L202 Hum-Lug rasputnica – Gornja Stubica, L203 Križevci – Bjelovar – Kloštar, L206 Pleternica – Požega – Velika i L208 Vinkovci – Gaboš – Osijek use the HZ series 7121 (Plavac). The passenger capacity for HZ series 7121 (Plavac) is 144. The average train occupancy in local railway traffic regardless of the route is set at 30%.
This was followed by a calculation of the relation between the railway infrastructure charges fees and total income of sold tickets. Since railway line L208 Vinkovci – Gaboš – Osijek is the only one categorized differently compared the the rest of the lines, it will be analyzed separately. The share of the charges fees is 9.99% which is a relatively reasonable percentage. If this line belonged to the rest of the railway lines, the share would drop to only 3.33 %.
It is interesting to note that the rest of the railway lines all belong to a single category, with charges fees share ranging from the incredibly low 2.24% to actual 10.74%. It can be determined that when using trains with a higher capacity (HZ series 7121) the share ranges between 2.24 and 4.23%, while in the lower capacity trains the share ranges from 6.76 - 10.74%.The charges fees share compared to the total income for all local railway lines is shown in Figure 3.

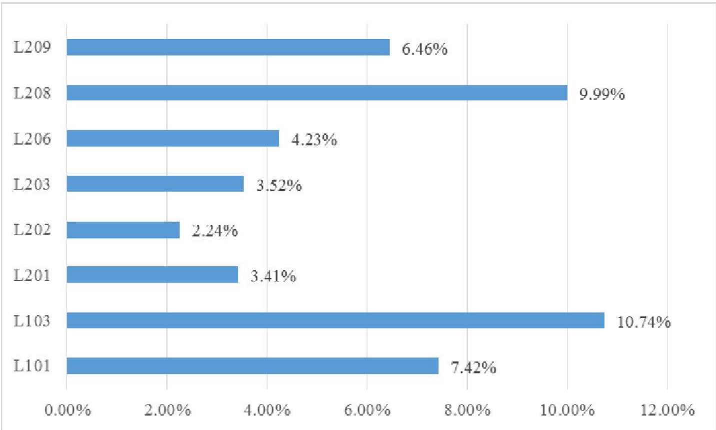


Fig. 3.
Share of infrastructure charges fees and income from ticket sale
Source: Authors

5. Conclusion

From the standpoint of the traffic policy of the EU, local railway lines occupy an important place in strategic goals, particularly considering the mobility of rural population and the ecological advantages of the railway over road transport.
This research has shown calculations of charges fees for railway infrastructure on local railway lines that run trains, and the total income based on the average train occupancy. The analysis of the obtained data shows that charges fees for using railway infrastructure are completely linear with the distance, train category and line parameter. This approach ensures an easier use of the fees and operators can understand the calculation with no difficulty. It might be a good idea to use the same line parameter on all railway lines. Furthermore, the analysis of the ticket sale income leads to the conclusion that the biggest problem is the low average train occupancy of merely 30%, so the income can only be boosted by increasing the number of passengers. The rise in ticket fares would deter passengers to other means of transport (bus or personal vehicle).
The set of measures to increase the number of passengers requires a complete change of the politics at the levels of state, local, and railway infrastructure, and the operators. The local traffic, namely, is regulated by strict laws in rural areas.

Finally, the relation between the charges fees for railway infrastructure use and the total income of ticket sales ranges from low 2.24 to 10.74%. This clearly indicates the strategy of railway infrastructure manager towards operators in terms of further development of railway traffic on local railway lines.

Acknowledgements

The paper is supported by the PROM – PRO research project "Adapting the railway system in the integrated passenger transport (ARSIPT)", that is solved at Faculty of Transport and Traffic Sciences, University of Zagreb.

References

Abramović, B. 2012. Liberalization of railway market as a challenge for the national operator. In *Proceedings of Globalization trends and their impact on the transport system in terms of the EU common market*, University of Žilina, Strečno, 12-18.

Abramović, B.; Šipuš, D. 2015. Proposal of improvements to mobility in the City of Sisak, *Železničná doprava a logistika - Railway Transport and Logistics*, 11(1): 4-11.

Andrejszki, T.; Csete, M.; Török, Á. 2014. Identifying modal shift by utility functions to reach an optimal point of regional development. In *Proceedings of the 14th International Conference "Reliability and Statistics in Transportation and Communication"*, Transport and Telecommunication Institute. Riga, 2-8.

Bugarinovic, M. & Boskovic, B. 2014. A systems approach to access charges in unbundling railways, *European Journal of Operational Research*, 240(3): 848-860.

Gašparík, J.;, Stopka, O; Pečený, L. 2015. Quality evaluation in regional passenger rail transport, *Naše More*, 62(3): 114-118.

Network Statement, HŽ Infrastructure Ltd. Available from Internet: <http://www.hzinfra.hr/network-statement-2016>.

Nikolova, C. 2008. User charges for the railway infrastructure in Bulgaria, *Transportation Research Part A: Policy and Practice*, 42(3): 487-502

Schwedes, Oliver et. al. 2014. *Öffentliche Mobilität Perspektiven für eine nachhaltige Verkehrsentwicklung*. Springer VS, Deutschland, 289 p.

White paper 2011 - Road map to a Single European Transport Area - Towards a competitive and resource efficient transport system. Available from Internet: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:HTML>.

THE COMPARISON OF THE PARKING SPACE DIMENSIONS TO THE MODERN CAR FLEET OF THE SELECTED EUROPEAN COUNTRIES

Radka Matuszkova[1], Michal Heczko[2], Michal Radimsky[3], Petr Kozak[4]
[1,2,3,4,] Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, Brno, Czech republic

Abstract: Nowadays there is a trend to buy and produce larger vehicles which provide the best comfort possible. This trend is, however, very slowly followed by dimensions of parking places with regards to standards changes and also with regards to economical behavior of developers. Developers tends to design parking spaces to fit in as many lots as possible, to do so, they use as small dimensions as limits allow. Paper analyzes vehicle fleet used in different countries and compares the most used vehicles to parking place dimensions.

Keywords: parking, width, length, parking place, vehicle fleet.

1. Introduction

The current trend is to manufacture and buy still bigger vehicles, which provide the best possible comfort. This trend is slowly followed by the size of parking spaces, by changes in regulations and national standards and followed by infrastructure investors. Investors tend to maximized marked parking spaces on parking lots by lowering dimensions of the parking spaces to the minimal values set by the national standards.
However, designing insufficient parking spaces, which doesn't correspond to the requirements of the current car fleet, may lead to a higher risk of traffic accidents, especially during the parking maneuvers. Another possible problem is a lower parking lot's turnover caused by more necessary car movements during parking. That is why the parking space dimensions set by the national standards in different European countries were compared to the cars dimensions inside modern car fleets in those countries (katalogautomobilu.cz, 2016). This paper doesn't compare the manipulation space of each parking stall and also doesn't cover the parking maneuvers.
The comparison of the parking spaces was done for these European countries: The Czech Republic, the Slovakia Republic, Germany, Poland, France, The United Kingdom and Italy. The countries were chosen to get the most diverse car fleets. For example, it is known that the Germans use bigger cars, and on the other side the Italians use smaller ones.

2. The analysis of the car fleet

The analysis of the car fleet was based on the statistic of the most selling cars during the last year (2015). Another possibility how to analyze the car fleet would be using the data from the state's central register, but these might not reflect the current trends of the newest vehicles. That's why the statistics of the most selling cars were chosen.
Twenty the bestselling vehicles from each country were selected and according to their technical specification their length and width were assigned to them (Bekker, 2016; Statista, 2016; Zverkova, 2016; Prokopec, 2016). Also the total number of sold vehicles for each car type was recorded. While only 20 the most selling car types were analyzed, the market share of analyzed vehicles was between 40 % and 54 %. Additionally, also the car fleet of whole Europe was analyzed (Bekker, 2016). The minimal and the maximal length and width were evaluated, together with an arithmetic average and a weighted arithmetic average of the vehicles.
The highest average width of a vehicle is in France, lowest in the United Kingdom, which is also same as the average in Europe (Fig.1.). The lowest weighted average of the vehicle width was in Italy, the highest in France. Between the top twenty bestselling vehicles was the widest in Poland (Ford Mondeo) and the narrowest in Italy (Fiat Panda).

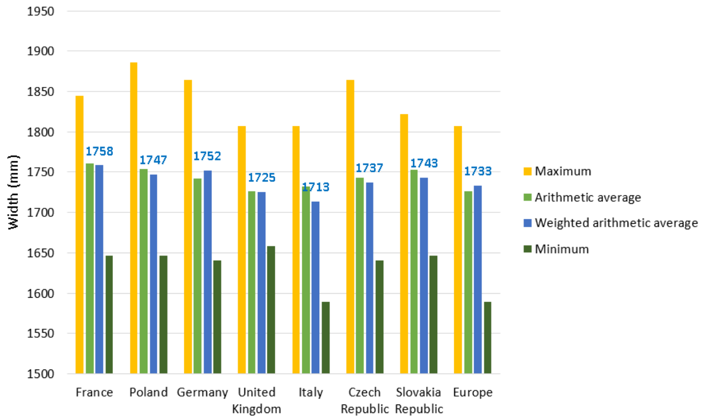


Fig. 1.
Width of vehicles
Source: (Authors)

[1] Corresponding author: matuszkova.r@fce.vutbr.cz

The highest average vehicle length was in Poland, the lowest in Italy. The lowest weighted average length was again in Italy and the highest weighted average length was again in Poland (Fig.2.). The longest model from the top 20 was sold in Germany (Audi A6) and the shortest in Italy (Fiat Panda).

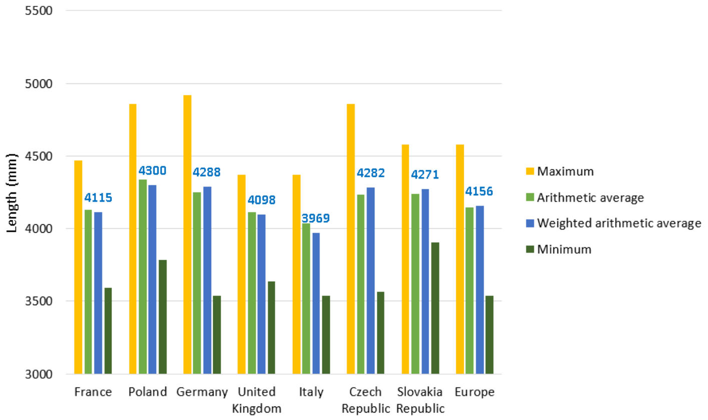


Fig. 2.
Length of vehicles
Source: (Authors)

The analysis of car dimensions confirmed that Italy has the lowest dimensions of the currently selling cars. Even lower than European in average. The analysis also showed that the highest car dimensions are in Germany and also in Poland.

2. The parking spaces requirements set by the national standards

2.1. Angle

The first criterion to compare the car dimensions is the selection of the angle of a parking space. Every one of analyzed national standards consider three basic angles 0° (parallel parking), 45° (angle parking) and 90° (perpendicular parking). Czech, Slovak and French national standard uses the same basic angles (Muller et al., 2011; Marrast et al., 2011). Different angles, like 60° or 75°, are mentioned only in some of the national standards. Only one national standard considers as the possible parking angle also angle lower than 45°, Italian regulation uses 30° (Leonardi et al., 2005). The British standard issued in 1992 also allowed to use 30° parking angle, however in the current standard (2016) is not mentioned anymore (Planning Service, 2015). Another exception is Germany, where the parking angles are set between 50 grads and 100 grads with 10 grads increments in-between (Schnabel et al., 2011).

2.2. Width

To determine the width of a parking space is used the basic model of a car without side view mirrors. Basic model is expanded by the space necessary for the door opening, which is shared with the neighbor parking space. Also the reserve space can be added when the parking space is next to a solid obstacle (like a wall or a pillar). This paper considers only the pure parking spaces without additional side spacing. Each of the national standards sets the dimensions of the basic car model and also the necessary space for a door opening or a cargo loading.
The width of perpendicular and angle parking spaces are between 2.2 m and 2.5 m. The exception is France where a parking space width for a perpendicular and an angle parking is different by 0.1 m, other states use the same width for both (Marrast et al., 2011). The width for a parallel parking is lower, between 2.0 m and 2.4 m. The interesting fact is that Poland and the United Kingdom use the same width for all three parking types, but in the Czech Republic or Germany are widths different by up to 0.5 m (Muller et al., 2011; Schnabel et al., 2011; Bykowski et al., 2011).

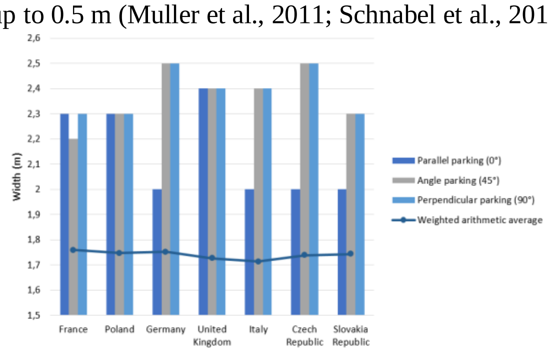


Fig. 3.
Width of parking space
Source: (Authors)

2.3. Length

To determine the length of the parking space is once again used the basic car model. For a perpendicular or an angle parking is added or subtract overhang of front/back bumper over wheels. When the parking space is next to a footpath, which is wide enough, the overhang is added, when there is a solid obstacle it is subtract.
The length set by the national standards is more diverse than the width. The longest spaces are mostly for the parallel parking, then the perpendicular parking and then the angle parking. For the parallel parking is length set between 5.0 m and 6.0 m, for the perpendicular parking between 4.5 m and 5.5 m and for the angle parking it is between 4.0 m and 5.5 m.

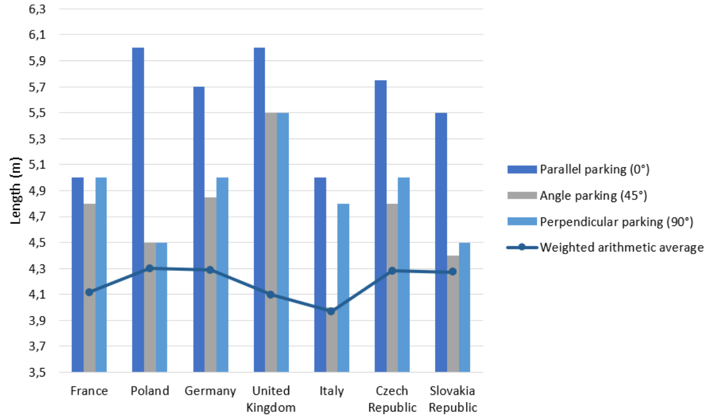


Fig. 4.
Length of parking space
Source: (Authors)

3. Conclusion

After the analysis of the car fleets in each country and the dimensions set by the national standards it is possible to do the conclusion. The following graph (Fig.3.) shows that the differences between the widths are not that significant in the different countries. While during the parallel parking it is considered to get out of a side of a vehicle and the width of the parking space is not so important, during the perpendicular or angle parking it is. Poland, Germany and the Czech Republic use almost the identical parking space dimensions, but the width used in Poland for the angle and the perpendicular parking is by 0.2 m lower than in the Czech Republic and Germany. The lowest difference between the width of the parking space and the width of the average modern car is in France, for the angle parking it is only 0,45 m.

The length dimensions are much more diverse. For example, Italy has the length of the angle parking same as is the weighted average length of Italian car fleet (Fig.4.). The longest cars are sold in Poland, Germany and the Czech Republic, which also correspond with the longer parking spaces. But in the United Kingdom, where are sold the second shortest cars among analyzed countries, the national standards set one of the longest parking spaces. Meaning that the United Kingdom leaves relatively big reserve for the parallel parking, especially when compared to the other European countries. The opposite situation with the parallel parking is in France and Italy, where the difference, between the average sold vehicle and the parking space size, leaves just one meter for the parking maneuver.

Acknowledgements

This paper has been worked out under the project No. FAST-J-16-2966 Assessment and design of parking space and project No. LO1408 AdMaS UP - Advanced Materials, Structures and Technologies, supported by Ministry of Education, Youth and Sports under the National Sustainability Programme I.

References

Bekker, H. 2016. 2015 (Full Year) Britain: Best-Selling Car Models. Available from Internet: <http://www.best-selling-cars.com/britain-uk/2015-full-year-britain-best-selling-car-models/>.
Bekker, H. 2016. 2015 (Full Year) Europe: 20 Best-Selling Car Models. Available from Internet: <http://www.best-selling-cars.com/europe/2015-full-year-europe-20-best-selling-car-models/>.
Bekker, H. 2016. 2015 (Full Year) France: Best-Selling Car Models. Available from Internet: <http://www.best-selling-cars.com/france/2015-full-year-france-best-selling-car-models/>.
Bekker, H. 2016. 2015 (Full Year) Germany: Best-Selling Car Models. Available from Internet: <http://www.best-selling-cars.com/germany/2015-full-year-germany-30-best-selling-car-models/>.
Bykowski, J.; Krawczynska, E. 2011. Technical aspects of the design of car parks at public buildings, *Drogownictvo*, 1: 8-13.

Planning Service. 2015. Parking Standards. Available from Internet: <http://www.planningni.gov.uk>.
Prokopec, P. 2016. Best-selling cars in the Czech Republic in 2015: 100 models of 94 brands. Available from Internet: <http://www.autoforum.cz>.
Katalogautomobilu.cz. 2016. Hypermedia: Catalogue car. Available from Internet: <http://peugeot.katalog-automobilu.cz/>.
Leonardi, S. et al.. 2005. *Car parks and rest areas,* Universita degli Studi di Catania, Catania, Italy.
Marrast, M. et al.. 2011. *French standard: building dimensions*, AFNOR, Paris, France..
Muller, M. et al. 2011. *ČSN 736056 Parking area,* Úřad pro technickou normalizaci, metrologii, státní zkušebnictví, Technicka Univerzita Ostrava, Ostrava, Czech Republic.
Schnabel, W.; Lohse, D. 2011. *Fundamentals of traffic engineering and transport planning,* Deutsches Institut fur Normung, Pforzheim, Germany.
Statista. 2016. Poland: ranking of car model sales 2015. Available from Internet: <http://www.statista.com/statistics/421398/poland-ranking-of-car-model-sales/>.
Zverkova, S. 2016. Best selling cars in 2015 in Slovakia. Available from Internet: <http://autobild.cas.sk >.

SESSION 16: TRANSPORT MODELING AND DECISION MAKING

THE LINK BETWEEN TRANSPORT NETWORKS' AND TERRITORIAL SYSTEMS' PROPERTIES

Vasile Dragu[1], Mihaela Popa[2], Ştefan Burciu[3], Cristina Oprea[4], Alina Roman[5]

[1,2,3,4,5] *Transport, Traffic and Logistics Department, Transport Faculty, University Politehnica of Bucharest, Bucharest, Romania*

Abstract: The increasing number and density of urban population due to the polarization of socio-economic activities led to an increased travel need. Satisfying the increased travel need within urban areas by using personal car led to an exacerbated growth of negative externalities with negative implications on life quality. Among the most irritating negative externalities of modern society we find congestion. Punctual solutions of developing infrastructures cannot be applied nowadays. One must find solutions like correlated development between urbanism and transport, reducing the need for travel, intermodality or modal distribution in favor of public transport modes. These goals can be achieved only if the public transport networks grow correlated with the served territory and become attractive for personal car users that can change their option of modal choice. The paper aims to define the transport networks' proprieties (conexity, connectivity, isotropy, homogeneity, nodality) and to put them in accordance with socio-economic characteristics. The case study examines how Bucharest's underground network development has been conducted (the network's proprieties for two moments of time are identified) so that it satisfies population travel needs and modifies the modal split in its favor. An analysis of the accessibility index within territory is realized by using the underground network's poles (directly accessible or with one transfer). Finally, a hierarchy of the underground network poles that are compared with the served areas characteristics is realized, setting up an intensity of the correlation.

Keywords: transport network, underground network, topology, network-territory link.

1. Introduction

The most irritating aspect of life for big cities inhabitants is traffic congestion. In 10 Romanian cities, the motorization rate is over 600 vehicles per 1,000 inhabitants. Bucharest became a city with more cars than Amsterdam, Copenhagen, Prague or Rome (Engineering Universe, 2015). Bucharest Metropolitan Transport Association proposed a plan that aims to create a complex public transport network in order to solve the actual congestion problems. A target for 2030 to increase the number of public transport users from 20%, today to at least 80%, has been set. This objective must be achieved in an area with the highest population density in the country – over 8000 inhabitants/km^2.

Unlike other consumer goods, the possession of a car has consequences beyond the private sphere. First of all, it can satisfy the people's travel need, enlarging activities space, and second of all, it can change the urban geographic form because of a strong relation between the motorization rate and urbanization. It states that the motorization rate can enhance the geographical link between urban zones (Yeh, 2009, Newman&Kenworthy, 1996, Raicu, 2007, Popa, 2009).

According to the Sustainable Urban Mobility Plan 2016-2030 – Bucharest-Ilfov Region, Bucharest was the city with the highest congestion in Europe in 2014 and one of the most affected cities in the world. This study presents the congestion index for some cities in the world, showing that Bucharest has a congestion index of 41%, occupying the 8th place (from 146 analyzed countries) in world rankings and the last place in Europe (Fig. 1).

With all this, in 2012 Warsaw was leading with a congestion index of 42%, followed by Marseille (40%) and Palermo (39%), while Bucharest was far behind them. While these cities were able to reduce their congestion level, the problem in Bucharest got worse.

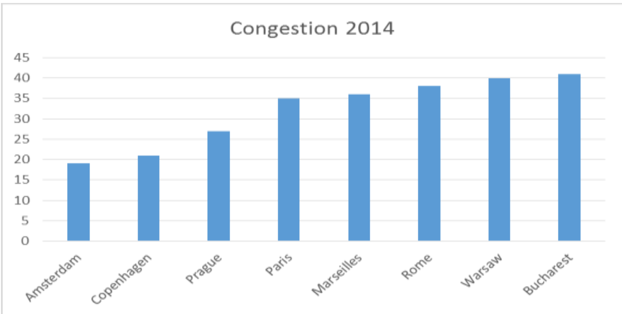


Fig. 1.
Congestion index
Source: Sustainable Urban Mobility Plan 2016-2030 - Bucharest-Ilfov

Dependency and the intensive use of private vehicle in daily trips accentuated externalities and led to unbearable congestion levels. Not long ago the congestion used to be reduced by developing the road infrastructure, not taking into

[1] Corresponding author: stefanburciu@yahoo.com

consideration that it is a limited resource that no matter how much it expands its capacity will always be reached. (Dragu et al., 2015).

In conclusion, transport externalities occur when the effective solicitation is near the analyzed element's capacity, in which case the dependence of the two no longer complies with reduced solicitations established laws (Raicu, 2007).

In the case of road traffic, when the effective solicitation approaches the road capacity, the congestion appears, reducing the capacity and worsening traffic conditions.

The classic measures of reducing congestion aim exclusively road infrastructures development leading to land occupation, natural landscape degradation, increased risk of accidents and attracting new traffic, which will reach again congestion, the process being cyclical until road infrastructure expansion is no longer possible. A vicious circle of possibilities to eliminate congestion is described (Raicu, 2005, Banister, 2008, Holden et al., 2013).

A severe difficulty in examining the dynamic relation between transport offer and demand is represented by the non-transferable character of the transport demand. This makes the offer of transport infrastructure impossible to be examined globally but only in relation with the topology and geography of a network that serves a territory. Between spatial distribution, technical and functional characteristics of infrastructure elements and the characteristics of the territory served, there are precise dependencies that may be expressed synthetically. If the network is presented as a planar graph then it is noted that both for arcs and for nodes, offer's quality parameters depend on the solicitation level (Raicu, 2007).

One of the most widespread measures for reducing the effects of congestion is to change the modal split in passenger transport by increasing the market share of high capacity public transport (metro, tram or light rail) in favor of individual transport with private vehicles. This can be achieved only when the corresponding transport networks are developed in accordance with the cities' development and faithfully serve the analyzed areas. There is an assertion according to which cities should not be allowed to develop more than they can be served by high capacity public transport (Khalil, 2012).

The present paper analyzes the development of Bucharest's metro network and the correlation of network parameters with the served territory parameters. The main properties of the transport networks are defined and one of them (connectivity) is calculated for the metro network, for different time horizons. The accessibility is also determined for different assumptions in making the trip (with or without transfer in a certain time period).

2. Transport networks characterization

Network is not only a consequence of technological innovation but a consequence of a planning idea that marks a connection between technical capabilities and territory covering (Raicu, 2007).

The ones participating in conceiving, developing and planning the networks are not fully aware of the essential links between networks and territories, ignoring almost completely the fact that networks serve the same territory and are part of the same social-economic framework.

The correlations between urbanism and public transportation need complex examinations that take into consideration traffic flows, infrastructure, transport means' and technologies' characteristics and also urban development as only together they determine transport system's performances.

By the relational properties assured by the network, in concordance with urban development logic, the territory is organized, space is differentiated and authority spreads.

Transport networks properties, essential for territory system functioning and assuring the correlations between networks and territory system evolution, are defined next.

A network serving a territory system can be characterized by conexity, connectivity, homogeneity, isotropy and nodality properties (Raicu, 2007, Raicu et al., 2010).

According to Dragu et al. 2011 *conexity, connectivity, homogeneity, isotropy and nodality* are defined and determined as follows:

Conexity is a topological concept from graph theory, which for network analyse is limited to strong and simple conexity; to the R network, adapted to S territory system, the G[R] orientated graph is associated, defined by the $[\rho_{ij}]$ matrix, with the elements $\rho_{ij} = 0$, if the a_i entrances do not depend on a_j exits and $\rho_{ij} = 1$, on the contrary.

G[R] is strongly conex if $(\forall)$ (i,j) , $i \neq j$ there is $\rho_{ij} = 1$, or $k, l, m, ..., s$ ($\neq i$ and j), for which ρ_{ik} x ρ_{kl} x ρ_{lm} x ...x $\rho_{sj} = 1$. The meaning is that of the existence of a road among i and j, so, a sequence of orientated links.

To define the simple conexity the R network is considered to have associated an unorientated graph G'[R], defined by $[\rho'_{ij}]$ matrix with elements: $\rho'_{ij} = 1$, if ρ_{ij} or $\rho_{ji} = 1$, $\rho'_{ij} = 0$, if ρ_{ij} or $\rho_{ji} = 0$.

The network is conex (simple conex) if $(\forall)$ (i,j) , $i \neq j$ there is $\rho'_{ij} = 1$ or $(\exists)$ $k, l, m,...,s$ ($\neq i$ and j) for which ρ'_{ik} x ρ'_{kl} x ρ'_{lm} x ...x $\rho'_{sj} = 1$. on the contrary R is no conex.

Conexity has an immediate signification as a transport network with this property interlocks different elements of territory system and assures the minimum condition of its cohesion.

Connectivity allows evaluating the multiplicity of the links assured by the transport network within territory system. Quantitative determinations of direct and alternative links offered by the network can be achieved. To establish connectivity α, γ and β indexes are used.

α index represents the ratio among the number of existing circuits in G'[R] graph and the maximum number of circuits that might exist in the graph for the same number of nodes;

- for the non-planar graph
$$\alpha_{np} = \frac{\sum_{i,j} \rho'_{ij} - n}{\frac{n(n+1)}{2} - n} \quad (1)$$

- for the planar graph
$$\alpha_p = \frac{\sum_{i,j} \rho'_{ij} - n}{2n-3} \quad (2)$$

Where; $\sum_{i,j} \rho'_{ij}$ **:** the number of links, $n+1$:bthe G’[R] graph number of nodes.

γ index is a measurement of the direct links assured by the transport network within the territory system. Adding a direct link among two nodes of the initial network, already connected (indirect), leads to creating a “net” (alternative links). γ index might be considered a measurement of net density and can be obtained as the ratio among G’[R] graph number of links and the maximum number of links possible in a graph with the same number of nodes;

- for the non-planar graph
$$\gamma_{np} = \frac{\sum_{i,j} \rho'_{ij}}{\frac{n(n+1)}{2}} \quad (3)$$

- for the planar graph
$$\gamma_p = \frac{\sum_{i,j} \rho'_{ij}}{3(n-1)}. \quad (4)$$

β index is the ratio among the number of links and the number of nodes of the G’[R] graph. It can be easily determined but the image for the network connectivity is less precise.

Homogeneity is the way different elements of the territorial system depend one on another by network, no matter particular characteristics of the links affecting space-time correlation. In other words, a_j entries must only depend on a_i exits no matter (i,j) time or space connection. Homogeneity is characterized by H(R) index, which can be defined for a link, a path or the whole network. This way, indexes for measuring the homogeneity rate of a part or of the whole network, were established: line losses, charge losses, depending on physical phenomena appearing in the network.

$$H(R) = \frac{1}{\sigma^2(\frac{d}{v})} = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}[\frac{d}{v} - (\overline{\frac{d}{v}})]^2} \quad (5)$$

Where; $\sigma^2\left(\frac{d}{v}\right)$: the chosen attribute dispersion (travel time on networks link, in this case).

Networks *isotropy* evaluates the links degree of equivalence under the aspects of assured relations among the system elements. A total homogenous network is also isotropic. In case of partial heterogeneousness the rate of isotropy can be determined. There is different isotropy for links between a_i and a_p elements. This isotropy rate can be evaluated starting from the considered roads’ homogeneity rate. In alternative routes hypothesis from a_i to a_p, $H(a_i \to a_p)$ will have more values, and the isotropy rate for $a_i \to a_p$ links might be determined with the following relation:

$$I(a_i \to a_p) = \frac{1}{\sigma^2_{H(a_i \to a_p)}} \quad (6)$$

Where; $\sigma^2_{H(a_i \to a_p)}$: $H(a_i \to a_p)$ dispersion.

Nodality allows characterizing networks’ nodes under relational capacities for the system aspect. Whether connectivity allows global evaluation of establishing direct and alternative routes among nodes for the entire network, nodality differentiate systems’ elements by the mutual relations among them. As nodality indexes one can identify: generalized nodality, Shimbel nodality, nodal accessibility (Raicu, 2007).

3. Case study

In the case study, the underground network connectivity (α, γ, β indices) was studied for 2009, and also for two expected development situations in 2017 and 2030, according to the estimations published on www.metrorex.ro.

In table 1 Bucharest underground network characteristics are presented. Table 2 contains Bucharest underground network connectivity indexes determined for the underground network associated graph, for the three moments of time.

Table 1
Bucharest underground network characteristics

Main lines		2009		2017	
		Length [km]	**Number of stations**	**Length [km]**	**Number of stations**
M1	Pantelimon – Dristor	29,1	22	29,1	22
M2	Berceni – Pipera	18,9	14	18,9	14
M3	Preciziei – Anghel Saligny	15,25	15	15,25	15
M4	Gara de Nord – Parc Bazilescu	3,7	4	6,1	6
M5	Eroilor – Drumul Taberei	-	-	6.8	9
	Total	66,95	55	76.15	66
Served urban area [km^2]		238		238	
Network density [km/km^2]		0,281		0,320	

Table 2
Bucharest underground network's connectivity indexes

Network topological characteristics		Present network	Projected network	
		2009	**2017**	**2030**
Number of nodes		12	13	24
Number of links		13	14	30
Connectivity indexes	alpha	0.015	0.013	0.021
	gamma	0.166	0.154	0.1
	beta	1.083	1.077	1.25

The underground network nodal accessibility was determined for the network to be commissioned in 2017, considering the network being described by its stations that represent the poles (45 poles in 2009 and 53 poles in 2017).
In figure 2 the underground network is presented by highlighting the three moments of time. In table 3 the accessibility of every sector is determined (for 2017) considering that the subway is the only transport mode used for travelling.

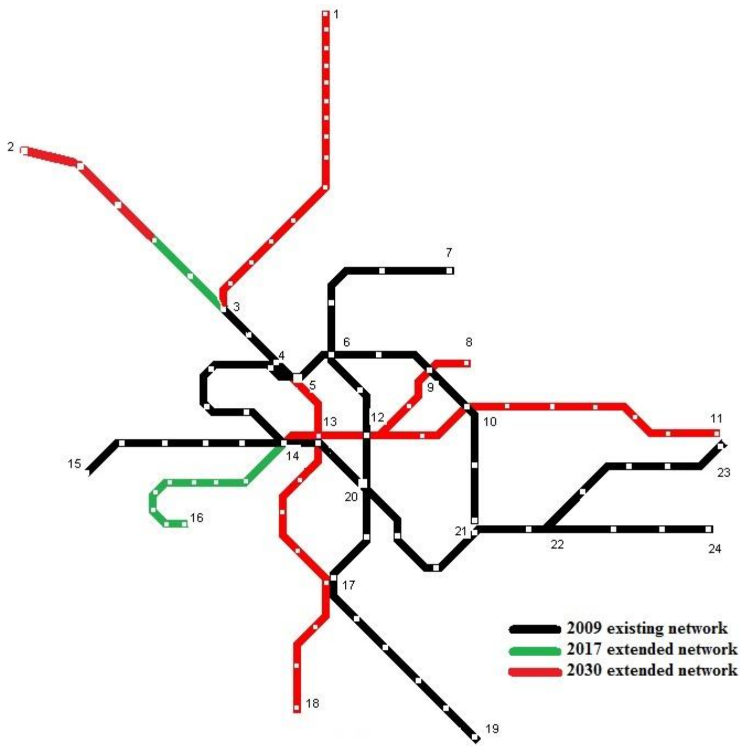


Fig. 2.
Bucharest underground network associated graph

Table 3
Underground network characteristics in every administrative sector (for 2017)

Pole \ Index		Station	NA	NL	PDA	PIA	FRV	PA 15 min	PA 30 min
1	Sector 1	1 Mai	2	1	5	19	20	6	14
2		Griviţa	2	1	5	19	20	7	17
3		Basarab	3	2	24	28	40	12	32
4		Piaţa Victoriei	4	2	32	20	40	15	34
5		Aviatorilor	2	1	13	28	20	8	27
6		Aurel Vlaicu	2	1	13	28	20	5	23
7		Piaţa Romană	2	1	13	28	20	10	33
8		Gara de Nord	2	2	24	28	30	13	30
9		Jiului	2	1	5	19	20	5	11
10		Parc Bazilescu	1	1	5	19	10	4	9
Total			**22**	**13**	**139**	**236**	**240**	**85**	**230**
1	Sector 2	Pipera	1	1	13	28	10	4	18
2		Ştefan cel Mare	2	1	20	32	20	10	32
3		Obor	2	1	20	32	20	7	31
4		Piaţa Iancului	2	1	20	32	20	6	31
Total			**7**	**4**	**73**	**124**	**70**	**27**	**112**
1	Sector 3	Piaţa Muncii	2	1	20	32	20	7	29
2		Dristor	3	2	28	24	50	15	37
3		Mihai Bravu	2	2	28	24	40	10	39
4		Nicolae Grigorescu	3	2	28	24	40	12	29
5		Titan	2	1	20	32	20	8	23
6		Costin Georgian	2	1	20	32	20	6	18
7		Republica	2	1	20	32	20	5	15
8		Pantelimon	1	1	20	32	10	4	13
9		Piaţa Unirii	4	3	40	12	60	18	46
10		1 Decembrie 1918	2	1	14	34	20	7	23
11		Nicolae Teclu	2	1	14	34	20	5	19
12		Anghel Saligny	1	1	14	34	10	4	15
Total			**26**	**17**	**266**	**346**	**330**	**101**	**306**
1	Sector 4	Timpuri Noi	2	2	28	24	40	12	43
2		Tineretului	2	1	13	28	20	10	35
3		Eroii Revoluţiei	2	1	13	28	20	8	31
4		C-tin Brâncoveanu	2	1	13	28	20	8	24
5		Piaţa Sudului	2	1	13	28	20	7	17
6		Apărătorii Patriei	2	1	13	28	20	6	14
7		Dimitrie Leonida	2	1	13	28	20	5	11
8		Berceni	1	1	13	28	10	4	8
Total			**15**	**9**	**119**	**220**	**170**	**60**	**183**
1	Sector 5	Izvor	2	2	28	24	40	14	46
2		Eroilor	4	3	36	16	50	12	44
3		Universitate	2	1	13	28	20	10	37
4		Academia Militară	2	1	8	28	20	5	25
Total			**10**	**7**	**85**	**96**	**130**	**41**	**152**
1	Sector 6	Crângaşi	2	1	20	32	20	9	37
2		Petrache Poenaru	2	1	20	32	20	8	38
3		Grozăveşti	2	1	20	32	20	9	40
4		Politehnica	2	1	14	34	20	10	31
5		Lujerului	2	1	14	34	20	7	27
6		Gorjului	2	1	14	34	20	6	22
7		Păcii	2	1	14	34	20	5	17
8		Preciziei	1	1	14	34	10	4	12
9		Orizont	2	1	8	28	20	6	23
10		Favorit	2	1	8	28	20	7	20
11		Tudor Vladimirescu	2	1	8	28	20	8	17
12		Parc Drumul Taberei	2	1	8	28	20	7	14
13		Romancierilor	2	1	8	28	20	6	11
14		Valea Argeşului	2	1	8	28	20	5	8
15		Drumul Taberei	1	1	8	28	10	4	8
Total			**28**	**15**	**186**	**462**	**280**	**101**	**325**

For every pole of the underground network 7 comparison criteria were considered:

- NA – number of links with the origin in a considered pol,
- NL – number of transport lines that cross a pole,
- PDA – number of direct accessible poles,
- PIA – number of poles accessible with one interchange,
- FRV – traffic frequency (number of trains that get through the pole in one hour),

- PA 15 min – number of accessible nodes in 15 minutes,
- PA 30 min – number of accessible nodes in 30 minutes.

For determining those criteria we considered a headway (I) of 6 min, the time lost per stopping at one station (t_{st}) of 30 sec, the station to station medium travel time (t_m) of 3 min and the transfer time (t_{tr}) of 6 min.
In table 4, the underground network characteristics for every administrative sector for the years 2009 and 2017 are presented. The characteristics for 2009 were determined in Dragu et al., 2011.

Table 4
Underground network characteristics in every administrative sector

Sector / Indice		Sect. 1	Sect. 2	Sect. 3	Sect. 4	Sect. 5	Sect. 6
Population [inhabitants]		225400	345400	385400	287800	271600	367800
Population density [inh./km²]		3220	10794	11335	8465	9053	9679
Number of poles 2009		8	4	12	8	3	8
Number of poles 2017		10	4	12	8	4	15
N A 2009		18	7	26	15	7	15
N A 2017		22	7	26	15	10	28
N L 2009		11	4	17	9	5	8
N L 2017		13	4	17	9	7	15
P D A 2009		121	73	266	119	69	130
P D A 2017		139	73	266	119	85	186
P I A 2009		172	94	232	210	56	196
P I A 2017		236	124	346	220	96	462
PA 15	2009	67	27	100	60	35	57
	2017	85	27	101	60	41	101
PA 30	2009	202	112	297	181	114	181
	2017	230	112	306	183	152	325

The accessibility for every sector at the two analyzed moments (2009 and 2017) is indicated in figure 3, for PA 15, and in figure 4, for PA 30.

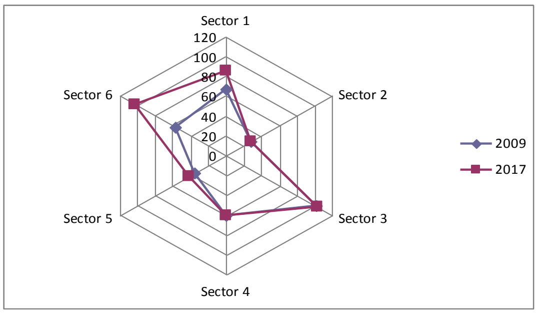


Fig. 3.
Administrative sectors accessibility PA 15 (2009 and 2017)

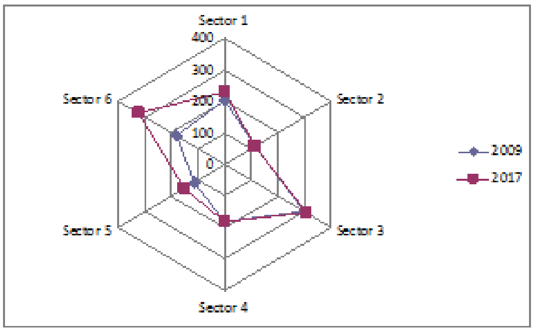


Fig. 4.
Administrative sectors accessibility PA 30 (2009 and 2017)

Analyzing figures 3 and 4 it can be seen that the accessibility for Sector 6 is considerably improved, while the nodes from Sector 2 have the smallest accessibility; the values for sectors 3 and 4 remain unchanged. In conclusion, it would be recommended that the following developments of the underground transport network would be made in the Sector 2 in order to realize an equilibrium regarding territory covering with high capacity public transport network.
Table 5 illustrates population values, population density and the accessibility of Bucharest administrative sectors.

Table 5
Demographic characteristics of administrative sectors

Sector	Population [inhabitants]	Population density [inh./km²]	Accessibility 2017	
			PA 15	PA 30
Sector 1	225400	3220	85	230
Sector 2	345400	10794	27	112
Sector 3	385400	11335	101	306
Sector 4	287800	8465	60	183
Sector 5	271600	9053	41	152
Sector 6	367800	9679	101	325

Adjustment functions and correlation coefficient (R2) between population, respectively density and accessibility for PA 15 and PA 30 are presented in table 6.

Table 6
Adjustment functions and correlation coefficients

Correlation / Adjustment functions	PA 15		PA 30	
	Population Number – Accessibility	**Population Density– Accessibility**	**Population Number – Accessibility**	**Population Density– Accessibility**
Linear	$y = 545.95x + 276138$ $R^2 = 0.0761$	$y = -13.746x + 9708.4$ $R^2 = 0.022$	$y = 314.31x + 245380$ $R^2 = 0.185$	$y = 0.9359x + 8553.6$ $R^2 = 0.0007$
Exponential	$y = 279011e^{0.0015x}$ $R^2 = 0.049$	$y = 9896.9e^{-0.0028x}$ $R^2 = 0.036$	$y = 252111e^{0.0009x}$ $R^2 = 0.146$	$y = 8233.2e^{-5E-05x}$ $R^2 = 8.00E-05$
Logarithmic	$y = 17675\ln(x) + 240911$ $R^2 = 0.0233$	$y = -1282.4\ln(x) + 14053$ $R^2 = 0.056$	$y = 46709\ln(x) + 65586$ $R^2 = 0.096$	$y = -546.34\ln(x) + 11662$ $R^2 = 0.006$
Polynomial of 2 degree	$y = 84.042x^2 - 10576x + 574218$ $R^2 = 0.691$	$y = 3.3191x^2 - 452.96x + 21480$ $R^2 = 0.458$	$y = 10.139x^2 - 4215x + 689802$ $R^2 = 0.801$	$y = 0.459x^2 - 204.11x + 28673$ $R^2 = 0.575$
Polynomial of 3 degree	$y = 1.8966x^3 - 281.43x^2 + 10655x + 212871$ $R^2 = 0.805$	$y = 0.1565x^3 - 26.836x^2 + 1298.8x - 8334.5$ $R^2 = 0.81$	$y = -0.0086x^3 + 15.636x^2 - 5310.8x + 757252$ $R^2 = 0.802$	$y = 0.0025x^3 - 1.129x^2 + 112.5x + 9185.7$ $R^2 = 0.614$
Polynomial of 4 degree	$y = 0.1437x^4 - 35.127x^3 + 3072.5x^2 - 114212x + 2E+06$ $R^2 = 0.992$	$y = 0.0062x^4 - 1.4345x^3 + 117.28x^2 - 4066.9x + 60052$ $R^2 = 0.968$	$y = -0.0011x^4 + 0.9621x^3 - 283.73x^2 + 33775x - 1E+06$ $R^2 = 0.862$	$y = -0.0001x^4 + 0.0912x^3 - 28.495x^2 + 3685.5x - 156663$ $R^2 = 0.841$
Power function	$y = 262414x^{0.0392}$ $R^2 = 0.0104$	$y = 20784x^{-0.2268}$ $R^2 = 0.068$	$y = 153823x^{0.1309}$ $R^2 = 0.069$	$y = 15289x^{-0.1184}$ $R^2 = 0.011$

From table 6 it can be seen that the curve that best adjusts the registered values, both for PA 15 and PA 30, is the polynomial function of 4th degree. The observation is that this function has many inflection points and can't make a rigorous forecast on future network's development, considering that the expansion of the network was realized within the underserved areas. The exception for future development is Henri Coanda airport that aims to satisfy a point of great attractiveness with high capacity public transport.
The correlation between population density and accessibility of Bucharest's 6 administrative sectors for PA 15 and for PA 30 is presented in figures 5 and 6.
In figure 5 it can be observed that there are 3 inflection points and a minimum point on the definition domain; in figure 6 there are 2 maximum points and one minimum point. The two functions most closely approximate the points with known values but the trust for future extrapolation is minimal because of the inflection points that limit the possibilities of extrapolation.

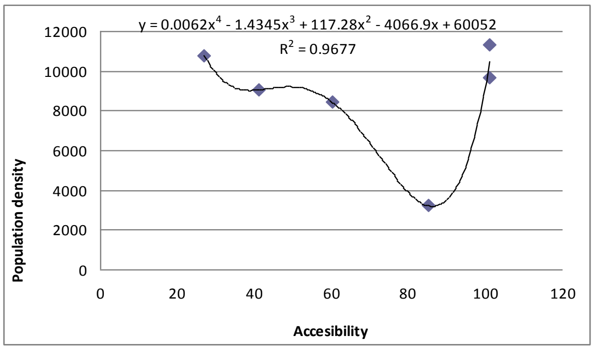


Fig. 5.
The correlation population density - accessibility for PA 15

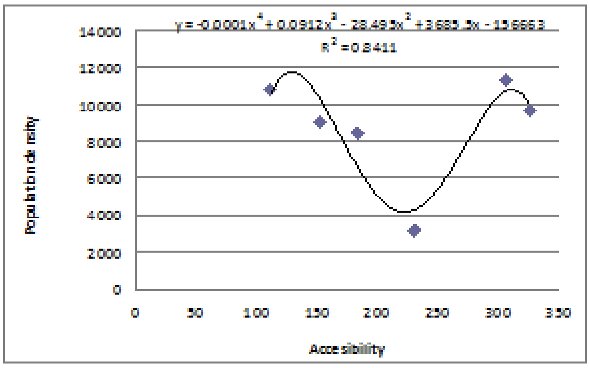


Fig. 6.
The correlation population density - accessibility for PA 30

4. Conclusions

By analyzing the underground network connectivity indices at the three moments of time, it can be concluded that the resulted values are small both in the present and the future, because the public authority is orientated to the extension of the network towards Bucharest adjacent villages and not to the multiplication of the existent links. The extension aims to increase the accessibility of Henri Coanda airport by developing a link between it and the city. In the network's extension for 2017 the connectivity indexes are smaller because in the extended network there were no alternative links that consolidate the network's density that is vulnerable in case of events that can disrupt circulation. The extremely low values of the connectivity indexes lead to the conclusion that the examined network is extremely vulnerable in terms of providing connections between areas and steps should be made to increase connectivity (multiplying the links) that support the development of a reliable network in terms of ensuring the travels' continuity in case of incidents.

From the accessibility point of view for PA 30, it can be seen that the network's development in 2017 led to changes in Sectors' hierarchy. In 2009 the Sectors' hierarchy was: S3, S1, S4, S6, S5, S2. By opening Drumul Taberei-Eroilor line the Sectors' hierarchy will be: S6, S3, S1, S4, S5, S2. Sector 6 occupies the first place, the last two places being occupied by Sector 5 and Sector 2 both in 2009 and 2017. The first position is argued by the construction of the new line exclusively in Sector 6, the accessibility being significantly improved. By analyzing the correlation population – accessibility (table 6) it can be concluded that there are no correlations between the elements using classical functions (linear, exponential, logarithmic or parabolic), this being highlighted by the extremely low value of the correlation coefficient R^2. In conclusion, the development of the metro network should be done with priority in Sectors 2, 4 and 5 that, according to figures 3 and 4, have the lowest values of accessibility.

References

Banister, D. 2008. The sustainable mobility paradigm, *Transport Policy*, 15(2): 73-80.

Dragu, V.; Stefanica, C.; Burciu, Ş. 2011. Accessibility study in regard to Bucharest underground network, *University POLITEHNICA of Bucharest Scientific Bulletin, Series D: Mechanical Engineering*, 73(1): 221-237.

Dragu, V.; Rosca, E.; Rusca, A. 2015. Public Transport - Feasible Solution for Sustainable Urban Mobility. In *Proceedings of the European Automotive Congress EAEC-ESFA 2015, Vol. II*, Spinger International Publishing Switzerland, 419-429.

Holden, E.; Liunerud, K.; Banister, D. 2013. Sustainable passenger transport: Back to Bruntland, *Transport Research Part A*, 54:66-77

Khalil, H.A. 2012. Enhancing quality of life through strategic urban planning, *Sustainable Cities and Society*, 5: 77-86

Newman, P.W.G.; Kenworthy, J. 1996. The land use-transport connection: an overview, *Land Use Policy*, 13(1):1-22

Popa, M. 2009. *Transport economy*, Politehnica Press, Eds., Bucharest, Romania.

Raicu, Ș. 2005-2007. *Promoting sustainable mobility in Bucharest metropolitan area*, CEEX Programme, contract 104/03.10.2005, beneficiary ANCS

Raicu, S. 2007. *Transport systems*, AGIR Eds., Bucharest, Romania.

Raicu, S.; Dragu, V.; Burciu, S.; Stefanica, C. 2010. About the characterization of urban public transport networks and their terminals, *The sustainable World, WIT Press,* 489-499.

Yeh, C.F. 2009. *Intermodalité et coûts des déplacements urbains dans les mégapoles - Les cas de Paris, Shanghai et Taipei*, Thèse de doctorat, Université Paris-Est, INSTITUT D'URBANISME DE PARIS, Ecole doctorate Economie, Gestion Et Espace – EGEE, Paris, France.

Sustainable Urban Mobility Plan 2016-2030 - Bucharest-Ilfov; Available from Internet: <http://www.pmb.ro>.

Engineering Universe, 2015. *Engineering Universe no. 17/1-15 september 2015*, AGIR Eds.

IMPACT OF POPULATION DEVELOPMENT AND EMPLOYMENT ON THE TRANSPORT PERFORMANCE IN THE EU

Bibiana Bukova[1], Eva Brumercikova[2], Pavol Kondek[3]
[1,2,3] Universty of Zilina, Faculty of Operation and Economics of Transport and Communication, Department of Railway Transport, Zilina, Slovakia

Abstract: The article is focused on chosen internal and external determinants of the EU transport market. The chosen external transport market determinants processed in the article include the economic development of the world economy, specification of the EU regions and countries, the GDP and the population trend in the EU. Internal determinants affecting the EU transport market affect the EU transport policy, state of the transport infrastructure and its development, new transport technologies and innovations, carriers' flexibility and their competitiveness. The problem area is very large, hence, the article is focused only on the analysis and prognosis of the external EU transport market determinants. The chosen external transport market determinants processed in the article are the population trend and the employment in the EU. The reason of the selection of the determinants is given by the authors' long-time research and also the actual development of the EU employment. The article shows regression models of the partial determinant impact on the EU transport performance. The impact is verified by the Fisher rule. The conclusion is focused on the estimation of the EU transport performance trend based on verified regression models.

Keywords: determinants, transport, population, employment, GDP.

1. Introduction

Globalization **-** as part of economic processes affects the three levels of world economy at the same time: the company level, the state level and the level of international trade. It significantly affects international relations, trade and of course transport. Transport is becoming an important element of a comprehensive system of international business, providing the meeting of the needs of subjects of the transport market (Brumercik, Lukac, Caban 2016).

2. The importance of transport

Europe needs efficient transport links in order to promote international trade and overall economic growth and thus is associated with the growth of employment of the population. The high level of transport infrastructure is the foundation of supply chains and the basis of the economy of each country. It enables efficient distribution of goods and the movement of the population. It ensures the availability of cities, unites and brings together the Europeans, while increasing their living standards (Cerna, Masek 2015). Table 1 shows the transport performance in passenger transport and also the index comparison of performances with the previous observed time period. The processed data in the table show that the transport performance of the EU 28 does not have a growing trend, more precisely the development is stable and at the same level. In certain years a performance increase can be observed, but it is not significant (Bukova, Brumercikova, Kolarovszki 2014).

Table 1
Comparison of transport performance of the EU

Year	Transport performance in bil pkm	index	Year	Transport performance in bil pkm	index
1995	5368,308228	-	**2005**	6288,346157	0,99710153
1996	5461,489667	1,017358	**2006**	6365,693328	1,012300082
1997	5576,832213	1,021119	**2007**	6460,098911	1,014830369
1998	5712,509141	1,024329	**2008**	6485,943587	1,004000663
1999	5859,33815	1,025703	**2009**	6492,032508	1,000938787
2000	5962,521004	1,01761	**2010**	6444,55578	0,992686924
2001	6063,889036	1,017001	**2011**	6480,083396	1,005512811
2002	6131,873717	1,011211	**2012**	6393,547942	0,986645935
2003	6196,979027	1,010618	**2013**	6464,992156	1,011174424
2004	6306,625724	1,017694			

Source: authors on the basis of statistics available on http://ec.europa.eu/eurostat

Figure 1 presents the percentage of different modes of transport of the total transport performances. Based on this chart it can also be stated that there is a minimum increase of transport performances in the EU 28.

[1] Corresponding author: bibiana.bukova@fpedas.uniza.sk

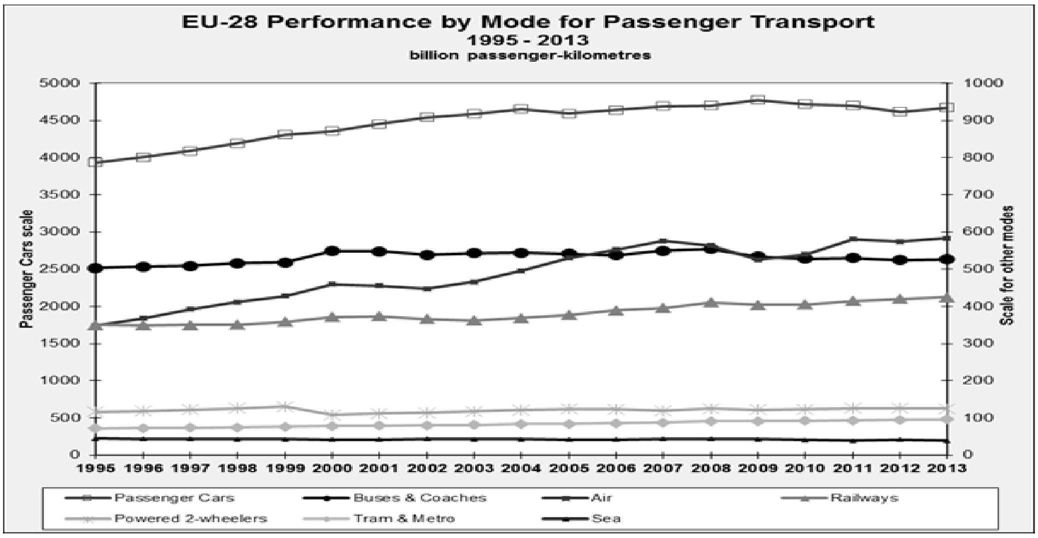


Fig. 1.
EU 28 performance by mode for passenger transport
Source: authors on the basis of statistics available on http://ec.europa.eu/eurostat

3. Development of population

The EU population aged over 60 years is now increasing twice as fast as before 2007 (by about two million every year compared to one million in the past). In regard to stating the dependence of the development of transport performances on the development of the population, specific data regarding the transport performance in passenger transport and the development of the population in the EU were processed in the following Table 2.

Table 2
Comparison of transport performance and the population of the EU

Year	**Population EU (28) in mil**	**Transport performance in bil pkm**	**Year**	**Population EU (28) in mil**	**Transport performance in bil pkm**
2000	486,830	5 963	**2008**	500,297	6 486
2001	488,052	6 064	**2009**	502,090	6 492
2002	488,963	6 132	**2010**	503,171	6 445
2003	490,692	6 197	**2011**	504,494	6 480
2004	492,556	6 307	**2012**	505,576	6 394
2005	494,598	6 288	**2013**	506,664	6 465
2006	496,437	6 366	**2014**	506,944	N/A
2007	498,301	6 460	**2015**	508,451	N/A
2008	500,297	6 486			

Source: authors on the basis of statistics available on http://ec.europa.eu/eurostat

Based on the processed data from Table 2, a development of passenger transport depending on the EU population was determined with different probabilities (96.58% and 81.22%). The result is graphically shown in Figure 2.

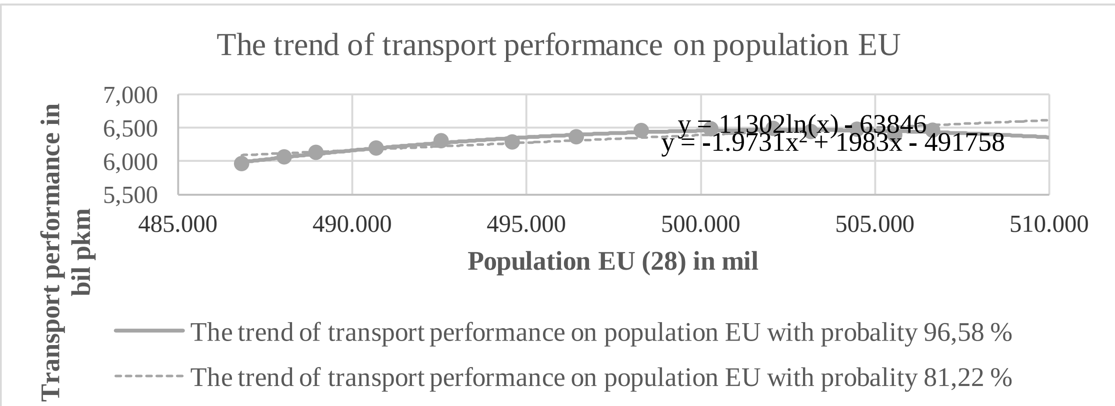


Fig. 2.
The trend of transport performance on the EU population

Figure 2 shows that if the EU population increased, the transport performances would decrease with a probability of 96.58%. However, if the population increased, the transport performances would have an increasing trend with a probability of 81.22%. As the population in the observed time period from 2000 to 2015 increased, it can be assumed that the transport performances will continue to increase in the future. Both trends were verified by the Fisher rule.

4. Employment of the population

Employment rates in Europe are reaching an average of 69% for people aged 20-64 years, which is significantly lower than in other countries of the world. Employed are 46% of older workers (aged 55-64 years) compared to 62% in the US and Japan. In addition, the employees in the EU have an average of 10% fewer working hours than the employees in the US or Japan.

The employment of citizens of the European Union (28 Member States) is being observed since 1997. As presented in Table 3 it had an increasing trend until 2008, when in 2009 it decreased due to the economic crisis, and this trend has continued until 2014, when in 2015 the employment began to increase again and reached the level of 70.1%. Table 3 is based on the information published on the Eurostat website. The table shows the transport performances in passenger transport, so that the regression role of the dependance of the transport performance on the employment could be processed (Figure 3).

Table 3

Employment rate, age group 20-64 in % and transport performance in bil pkm, EU 28

Year	Employment rate, age group 20-64, in %, EU 28	Transport performance in bil pkm	Year	Employment rate, age group 20-64, in %, EU 28	Transport performance in bil pkm
2001	66,9	6 064	2009	69	6 492
2002	66,8	6 132	2010	68,6	6 445
2003	67	6 197	2011	68,6	6 480
2004	67,3	6 307	2012	68,4	6 394
2005	67,9	6 288	2013	68,4	6 465
2006	68,9	6 366	2014	69,2	N/A
2007	69,8	6 460	2015	70,1	N/A
2008	70,3	6 486			

Source: authors on the basis of statistics available on http://ec.europa.eu/eurostat

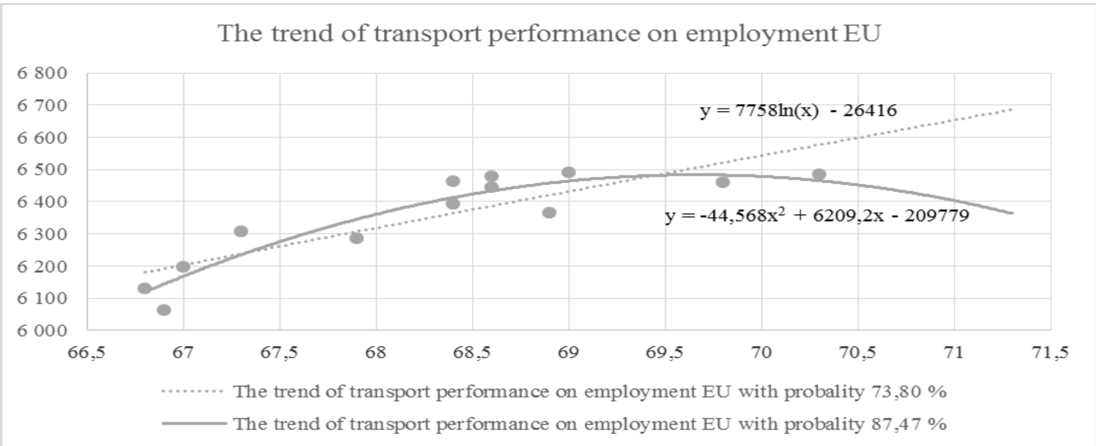


Fig. 3.

The trend of transport performance on the EU 28 employment

Figure 3 shows that if employment increased by 1%, then the probability of reducing the transport performances would be 87.47%. This fact will apparently not occur. The transport services in the time period from 1995 to 2013 were almost constant, only with minor diversions. The second trend with a probability of 73.80% assumes an increase in the transport performance together with an increase of employment of the population of the EU 28. Both trends were verified by the Fisher's rule.

5. Conclusion

The European Commission assumes that by 2020, the employment of the population aged 20-64 years will increase to the level of 75%. Based on the stated trend such a result is unrealistic. The optimistic trend is that the employment will rise, in 2015 it was 70.1% and in 2016 the assumed increase should reach 71.50%. In case of the assumption for 2020, the trend with the lower probability assumes the employment rate of 72.60% and the trend with the probability of

82.68% projects the employment rate of the EU population in 2020 of only 67%, which is 8% less than the stated objective of the European Commission.
Another indispensable factor is the sustainable mobility - which represents the implementation of the principles and objectives of a sustainable development in transport and economic policy with the focus on forming resources and effective use of investments both in transport infrastructure, as well as the development of transport services. Factors affecting the development of transport include the liberalization of the transport market and harmonization of legislative, technical and operational conditions, new forms of international business and new forms of technology management, introduction of intelligent transport systems and the level of transport telematics (Bukova, Brumercikova, Kondek, 2016).
The lack of competition and extensive state regulation combined with state ownership in the past resulted in a slow reaction of railroad "monopolies" to the changing demands and needs of carriers, leading to the decline of interest in rail transport and an increased use of a more flexible road transport.
The trends in transport depend on the development of the EU industry, changes in price sensitivity, changes in the demand for transport services and the quality of additional services of carriers (Bukova, Brumercikova, Kondek, Sojcak 2016)
Finally, we include a statement of the European Central Bank, in particular on their website www.ecb.europa.eu: "Globalisation is a challenge not only for the EU countries and transport companies but also for multinational companies. If the EU wants to succeed in global competition and respond to the challenges of globalization, it must implement reforms in the areas of tax, labor, energy and transport infrastructure. The reforms reflect the necessary changes to the functioning of the EU and reflects the challenges given to the EU by globalization of the world economy."

Acknowledgements

This paper was supported by the VEGA Agency, Grant No. 1/0701/14 “The impact of the railway freight transport market liberalization on the social transport costs”

References

Brumercik, F.; Lukac, M.; Caban, J. 2016. Unconventional powertrain simulation, *Communication – Scientific letter of University of Zilina*, 18(2): 30-33.
Bukova, B.; Brumercikova, E.; Kolarovszki, P. 2014. *Spedition and Logistics* (In Slovak), Wolters Kluwer, Bratislava, Slovak Republic.
Bukova, B.; Brumercikova, E.; Kondek, P. 2016. *Entrepreneurship in transport*, ReliantGroup, Praha, Czech Republic.
Bukova, B.; Brumercikova, E.; Kondek, P.; Sojcak, D. 2016. The impact of international intrepreneurship on the development of transport, *Communication – Scientific letter of University of Zilina*, 18(2): 139-142.
Cerna, L.; Masek, J. 2015. The proposal the methodology of the supply chain management in transport and logistics company. In. *Proceedings of the Transport means –international conference*, 567-570.

TRAFFIC SPEED PREDICTION USING PROBABILISTIC GRAPHICAL MODELS

Lukáš Rapant[1], Tomáš Martinovič[2], Kateřina Slaninová[3], Jan Martinovič[4]

[1,2,3,4] *IT4Innovations National Supercomputing Center, VŠB - Technical University of Ostrava, Ostrava - Poruba, Czech Republic*

Abstract: The importance of traffic state prediction steadily increases together with growing volume of traffic. The ability to predict traffic speed and density in short to medium horizon is one of the main tasks of every Intelligent Transportation System. Many such systems are currently developed to monitor and control the traffic flow in various states. It is also very important for dynamic route planning applications. Basically, there are two possible approaches to this prediction. The first is to utilize physical properties of the traffic flow to construct a numerical model. This approach is, however, very difficult to implement. Due to the problems with traffic sensor density, it is very difficult to gather enough data to accurately describe the starting and boundary conditions of the model. The other option is to use historical traffic data and relate information and patterns they contain to the current traffic state by the application of some form of statistical or machine learning approach. Authors propose a solution to use a probabilistic graphical models (PGM) for this task. These models are naturally able to capture all complexities in the traffic and incorporate uncertainty of the traffic data. This paper presents an algorithm based on dynamic Bayesian networks (DBN), which are one of the most widely used PGMs for modelling of dynamical systems. Our algorithm was tested on real data coming from the Czech Republic motorways.

Keywords: probabilistic graphical models, Bayesian networks, hidden Markov models, traffic speed prediction, ASIM, FCD.

1. Introduction

One of the main tasks of Intelligent Transportation Systems is to predict state of the traffic in short to medium horizon. This prediction can be then utilized in various areas of traffic modelling, analysis, and management. There are two general approaches to this prediction. The first approach requires us to have an exact mathematical description of the traffic flow and its starting and boundary conditions. Examples of this approach is article written by (Tang et al., 2014). This approach is feasible in simple traffic situations but quickly becomes intractable in case of inaccurate or incomplete data regarding both conditions. The second possible approach to traffic state prediction is to use historical data about traffic and relate them to the current state of the traffic by application of some statistical or machine learning approach. Example of this approach is described by (Huang, 2015). This task is, however, also not a simple one. It is complicated by complex nature of the traffic data. They can, depending on type of their source, be inaccurate or not available in required quantity. Despite this fact, this approach is preferable in case of traffic state prediction on Czech Republic motorways due to the unavailability of boundary condition data (i.e. there are not measurements on all ramps leading to and out of motorway).

Important part of any traffic state prediction is traffic data availability. Generally, data sources describing actual traffic situation on Czech motorway can be divided into two groups - stationary data sources (ASIM sensors) and floating car data sources (Floating Car Data).

ASIM sensors are placed on certain toll gates (all these toll gates are placed on the motorways). They comprise of various sensors like passive infrared detectors and radars. They are able to distinguish individual vehicle types, and measure their speed and intensity. Their measurements are aggregated every five minutes and mean speed and intensity are calculated. They have many advantages. Perhaps most important advantage is that there is no need for equipping vehicles with additional electronic devices. Consequently, a sensor measures speed of all vehicles going through it. The second important advantage is a detail of the data. ASIM sensors provide separate information about every lane of the monitored road and can distinguish individual vehicle types. However, these sensors have some serious disadvantages. The ASIM sensor network is very sparse. There are only about 120 toll gates equipped with ASIM sensors; all of these are placed on the motorways. There are also other limitations. Electronic toll gates divide roads into segments of various length, some of them may have length of many kilometres. Thus, data obtained from ASIM sensors exactly describe only traffic situation around the tollgate.

The other available source is Floating Car Data (FCD). The floating car data (FCD) technique is based on the exchange of information between floating cars traveling on a road network and a central data system. The floating cars periodically send their positions and speed, whereas the central data system spatially and temporally aggregates the received data. The frequency of sending/reporting is usually determined by the resolution of data required and the method of communication. FCD have specific discretization. For example, D1 motorway is divided into the sections (TMC segments) with length from several hundred meters to few kilometres. The traffic speed is calculated each minute as a mean of speed of all floating cars that passed through the section in the last minute.

This approach has also several advantages and drawbacks. The number of cars equipped with a GPS unit has doubled over the past five years. It can be expected that the trend will continue. It implies that the number of potential data sources will increase. Moreover, data from GPS receivers is not limited to the predefined places so the coverage is much larger than in the case of the stationary data. Drawbacks come mostly from the use of GNSS technology. GPS

[1] Corresponding author: lukas.rapant@vsb.cz

device can fail to provide precise outputs. This imprecision can have an impact on positioning, ranging from meters to tens of meters and influence the car to segment assignment within the aggregation system. Also it means that it is impossible to identify the lane in which the car is. Because GNSS is based on satellite technology, GPS receiver has to be able to receive signals from several satellites. This can prove to be difficult in some cases (cities, forests).

Both of these data sources are available to us thanks to the viaRODOS[2]. Nature of these data sources limits us in several ways. Given the positioning of the ASIM sensors and properties of FCD, it is impossible for us to use any kind of exact model. Moreover, because FCD contain only information about speed, the predictions are limited only to traffic speed. Therefore, focus of this paper is to find the algorithms that can exploit all the possible information contained in the historical and the current traffic data available for Czech Republic motorways to make a short term traffic speed prediction on motorways. A proposed solution is based on special kind of probabilistic graphical model called dynamic Bayesian network (DBN), because it provides a way to naturally utilize both of the data sources.

A lot of work has already been done in this area. Wang and Kuang (Wang and Kuang, 2015) proposed a traffic prediction method based on complex event processing and Adaptive Bayesian networks. They use synthetic data from the SUMO traffic simulator to evaluate their algorithms. On the other hand, Hoong et al. (Hoong et al., 2012) propose to use Bayesian Network for road condition prediction. They presented a set of evidences that could potentially be utilized for road condition prediction and constructed a Bayesian Network model to predict road conditions. Zhu et al. (Zhu et al., 2016) utilize a linear conditional Gaussian (LCG) Bayesian network model. Advantage of this model is its ability to work with continuous variables rather than discrete. However, learning of such model requires more and better data and therefore authors used data from macroscopic simulation. Paper written by Castillo et al. (Castillo et al., 2008) describes the problem of predicting traffic flows and updating these predictions when information about origin-destination pairs and link flows becomes available. They propose to use Gaussian Bayesian network to deal with this problem. They, however, also work with synthetic data on a small problem. Shiliang et al. (Shiliang et al., 2005) are using combination of Pearson correlation coefficients, Gaussian Mixture Model (GMM) and the Competitive Expectation Maximization (CEM) algorithm to approximate their joint probability distribution of traffic flow in the traffic network. They are utilizing both the spatial and temporal information of the data from the small network in Beijing. Wang et al. (Wang et al., 2015) use model similar to ours, but instead of coupled network built on spatial information, they work with similarity of road segments. They use spectral clustering to find this similarity. The closest to our work is the paper written by Herring et al. (Herring et al., 2010). They also use DBN for the prediction but instead of speed work with travel times. Their DBN, however, has Gaussian observations but much fewer hidden states. They also work with less complex data.

2. Probabilistic graphical models

There are many kinds of probabilistic graphical models but for the purposes of this article, our focus will be pointed to dynamic Bayesian networks, which are a special case of general Bayesian networks.

2.1. Bayesian network

A Bayesian network is a graphical model that represents conditional independences between a set of random variables. Let us consider four random variables A, B, C, and D. The joint probability can be factored as a product of conditional probabilities:

$$P(A,B,C,D) = P(A)P(B \mid A)\,P(C \mid B,A)\,P(D \mid C,B,A). \tag{1}$$

This factorization, however, does not tell us anything useful about the joint probability distribution because each variable can be potentially dependent on every other variable. So let us consider the following factorization:

$$P(A,B,C,D) = P(A)P(B)P(C \mid A)P(D \mid C,B). \tag{2}$$

This factorization implies a set of conditional independence relations. A variable or set of variables X is conditionally independent from Y given Z if $P(X,Y \mid Z) = P(X \mid Z)P(Y \mid Z)$ for all X, Y and Z such that $P(Z) \neq 0$. With this factorization it can be shown that given the values of B and C, A and D are independent:

$$\begin{aligned} P(A,D \mid B,C) &= \frac{P(A,B,C,D)}{P(B,C)} = \frac{P(A)P(B)P(C \mid A)P(D \mid C,B)}{\int P(A)P(B)P(C \mid A)P(D \mid C,B)\,dA\,dD} \\ &= \frac{P(A)P(C \mid A)P(D \mid C,B)}{P(C)} = P(A \mid C)P(D \mid B,C) \end{aligned} \tag{3}$$

[2] http://www.rodos-it4i.cz/defaultEN.aspx

A Bayesian network (BN) is a mean to represent a particular factorization of a joint distribution by a graph. Each variable is represented by a vertex in the graph. A directed edge is drawn from node X to node Y if Y is conditioned on X in the factorization of the joint distribution. To represent the factorization from Eq. 2, edge would be drawn from A to C but not from A to D. The Bayesian network representing this factorization is shown in Fig. 1.

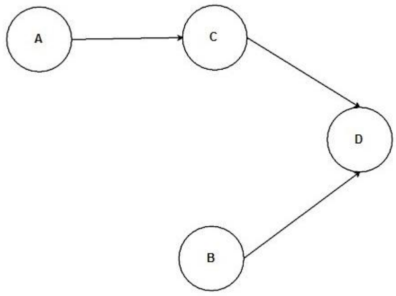


Fig. 1.
Example Bayesian network

Important property of the BN is that its graph can be considered as representation of the joint probability distribution for all variables. The tool to express this joint probability, as the product of the conditional probabilities that need to be specified for each variable, is called the chain rule:

$$P(X_1,\ldots,X_n) = \prod_{i=1}^{n} P(X_i \mid Par(X_i)) \tag{4}$$

Where; $Par(X_i)$: the parent set of a node X_i. Then the conditional probabilities, the structure of the BN, and joint probability distribution can be used to determine the marginal probability or likelihood of each variable holding one of its states. This procedure is called marginalization.
The true power of BN is shown whenever one of these marginal probabilities is changed. The effects of the observation are propagated throughout the network. The probabilities of a various neighbouring node are updated in every propagation step. In case of simple BN, the marginal probabilities or likelihood of each state can be calculated from the knowledge of the joint distribution, using the product rule, and the Bayes' theorem. Therefore, to define a BN it is necessary to specify the Conditional Probability Distribution (CPD) or pdfs of each node that has parents in addition to the prior probability of root vertices.
There are two important actions that can be performed with BN. The first is called inference. One of great strength of BN is that the conditional dependencies between variables can be inferred by visually inspecting the graph. Therefore, set of BN vertices can be divided into non-overlapping subsets of conditionally independent nodes. This decomposition is a basic part of the probability inference, which is the task of computing the probability of each state of a vertex in a Bayesian network when the values of other vertices are known. The second step to perform inference is the belief propagation. Belief propagation is the action of updating the beliefs in each variable when observations of some other variables are given. Inference in BN can be done by 2 classes of methods. The first and the most usual one is the exact probability propagation in a singly connected network. To do this, the network need to be transformed into singly connected structure. In the other class there are some approximate inference techniques (Monte Carlo inference techniques, inference by ancestral simulation, Gibbs sampling, Helmholtz machine inference,..).
The second one is called learning. All of the conditional probabilities in the BN are usually not known. Therefore, some learning techniques that enable us to complete the missing beliefs in the network must be employed. The role of learning is to find and adjust the parameters of the BN so that the pdfs defined by the network sufficiently describe statistical behaviour of the observed data. This procedure is usually realized by some form of EM algorithm.

2.2. Dynamic Bayesian network

Dynamic Bayesian Network (DBN) is a name of a model describing a system that is dynamically changing over time. DBN are usually defined as a special case of singly connected BN specifically designed for modelling the dynamic systems. All the vertices, edges and probabilities that make a static interpretation of a system are identical to a BN. Variables in DBN are called the state of a DBN, because they include a temporal dimension. These states satisfy the Markovian condition, which states that the state of a system at time t depends only on its previous state at time t-1. This property defines the First order Markov property: the future is independent of the past given the present.
The BN model is expanded by this fact. DBN allow not only connections within time slices, but also connections between time slices. These temporal connections introduce condition probabilities between variables from different

time slices. These time dependencies are represented by the transition matrix which is called a Conditional Probability Table (CPT), since it represents the CPD in tabular form. Static CPDs can also be represented by CPTs.
As with static BN, the states of a dynamic one do not need to be directly observable. There might be influencing factors of other variables that can be directly measured or calculated. Moreover, the state of dynamic system does not need to be a unique and simple state. It may by looked at it as a complex structure of interacting states. Each state in a DBN at one time slice may depend on one or more states at the previous time slice and on some states at the same time slice. So, generally speaking, in DBN the states of a system at time t may depend on system's states at time t-1 and possibly on current states of some other nodes in the fragment of DBN structure that represents variables at time t.
DBN can be described by probability distribution function on the sequence of T hidden-state variables $X = \{x_0, \ldots, x_{T-1}\}$ and the sequence of T observable variables $Y = \{y_0, \ldots, y_{T-1}\}$, where T is the time boundary for our model. This can be written as:

$$P(X,Y) = \prod_{t=1}^{T-1} P(x_t \mid x_{t-1}) \prod_{t=1}^{T-1} P(y_t \mid x_t) P(x_0) \tag{5}$$

Where; $P(x_t \mid x_{t-1})$: state transition pdfs, $P(y_t \mid x_t)$: are observation pdfs that specify dependencies of observation nodes regarding to other nodes at time slice t, $P(x_0)$: an initial state distribution. The first two parameters had to be determined for all states in all time slices. Conditional pdfs can be time dependent or time independent. Time independent conditional pdfs can be parametric or nonparametric, when they are described using probability tables. A DBN can be discrete, continuous, or combination of these two depending on the type of the state space of hidden and observable variables. The similar tasks can be performed with DBN as with BN:

1. Inference, estimation of the pdfs of unknown states given some known observations, and initial probability distribution,
2. Learning, estimation of parameters of a DBN such that they best fit to the observed data, and make the best model for the system,
3. Decoding, finding the best-fitting probability values for sequence of hidden states that have generated the known sequence of observations,
4. Pruning, distinguishing which nodes are semantically important for inference in DBN structure, and which are not, and removing them from the network.

In case of our application, the most important tasks are inference and learning.

3. Algorithm

Now let us present you how our algorithm works. As it has already been mentioned, proposed algorithm is based on use of both historical and current traffic data. These data are represented by speed time series coming from the two available sources: ASIM sensor network and FCD. Both of these sources have important roles in our model. ASIM sensors provide reliable information but, as a standalone information source, suffer from the two disadvantages. The first is spatial one, i.e. their network is sparse and is not covering equidistantly the motorway. The second is temporal one as the ASIM sensors have longer aggregation period and therefore are not optimal for online prediction. This problem can be fixed with FCD, which are available for all sections of the Czech Republic motorways and have much shorter aggregation period. However, these data can be quite inaccurate due to the lower penetration of the traffic by floating cars or other technical issues. Therefore, ideal prediction algorithm can utilize both the accurate but localized ASIM sensor data and widely available FCD, which suffer from the fact that they only measure speed of part of the traffic flow.
Solution for this problem was found in the form of dynamic Bayesian network also called coupled hidden Markov model. The example structure of the network can be seen in Fig. 2. Each vertex represents segment of the road. Edges are drawn in such way that future speed value of the segment depends on its last value and last values of its neighbouring segments. Hidden states represent true state of the traffic described by ASIM sensor data and measurements are observed noisy data represented by FCD. Both of these data sources are used during the learning of the network. One of the advantages of this model is that parameters of the model can be learned even when there are no ASIM sensors on some of the segments i.e. some of the hidden states are not observable at all. When properly trained, this network is able to predict the true state of the traffic speed (i.e. hidden state) from the n last values of FCD measurements.

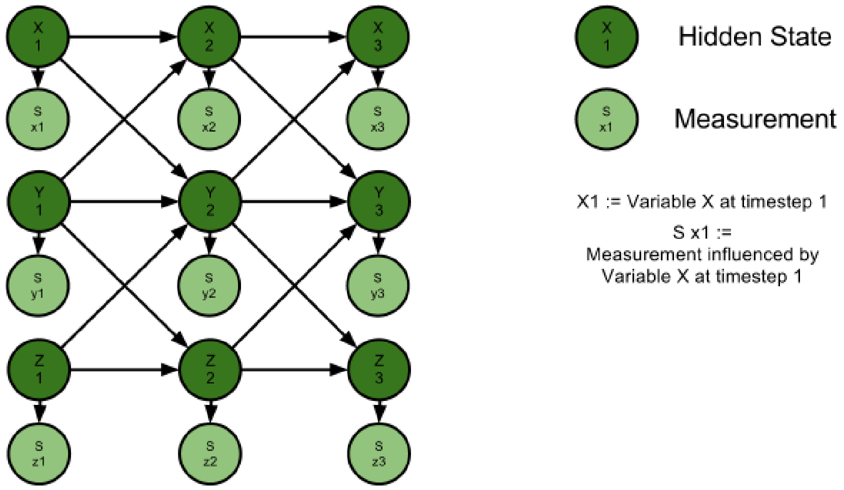


Fig. 2.
Coupled hidden Markov model as DBN
Source: (http://social.microsoft.com/Forums/getfile/103119)

General progress of our algorithm can be summarized into following steps:

1. Learning data pre-processing
2. Learning of the networks
3. Online prediction

Let us go through individual steps of the algorithm more thoroughly. In the first step, ASIM data and FCD are pre-processed for use in our network. This means that both of these continuous variables have to be transformed to discrete ones with m and n values for hidden and measurement nodes respectively. These numbers must not be too high, because the number of parameters in such model rises steeply (model requires $N \cdot m + N \cdot n + N \cdot n \cdot m + (n - 2) \cdot n^4 + 2n^3$ parameters) and it may not be possible to learn all these parameters in reasonable time. Some other works also use continuous observations (measurements) but we have decided to utilize simpler method to ease the learning of the network. The discretization is usually done by rounding the speeds to a certain number (i.e. 5 km/h). However, as it is evident from the Fig. 3, most of the measurements of ASIM sensors are distributed between 80 km/h and 130 km/h. Therefore, such rounding would produce few states with reasonable probability and greater number of improbable states. To address this issue, discretization based on probability density is proposed. State discretization will be smoother in areas with higher probability density and coarser otherwise. For example, if the speed is less than 60 km/h, it would be rounded to nearest multiple of 20 km/h and if the speed is higher than 60 km/h, it would be rounded to nearest multiple of 5 km/h. This procedure should result in states with reasonable probability. The data are also divided into 4 portions (data from 6:00 to 10:00, data from 10:00 to 14:00 and data from 14:00 to 18:00 and the rest, which is not used for prediction). This is done because the traffic speed time series are highly nonstationary and therefore creating only single model for all day would produce remarkably worse results. These periods are also naturally identifiable as morning peak, noon off-peak and afternoon peak.
The next step is the learning procedure of our model. Three separate models are learned, each for different period of the day. The learning procedure is done by EM algorithm and is done offline. EM algorithm is ideal for this problem because it can handle incomplete or unobserved data.
In the last step of our algorithm, special inference task called prediction is performed. In terms of our network, it means finding:

$$P(x(i, t + T) \mid y(:, 1{:}\, t)), \tag{6}$$

Where; $x(i, t + T)$: hidden state of node i at time t+T, $y(:, 1: t)$: represents measurements from the time period foregoing the prediction. Predicted value for each hidden variable is then calculated by maximum a posteriori decision rule (MAP) as:

$$z_i = \underset{k \in \{1,..m\}}{\operatorname{argmax}} P_k(x(i, t+T) \mid y(:, 1{:}\, t)), \tag{7}$$

Where; $P_k(x(i, t+T) \mid y(:, 1: t))$: the probability of hidden variable i at time t+T be at state k. This approximate inference is performed by The Boyen-Koller algorithm (Boyen and Koller, 1998).

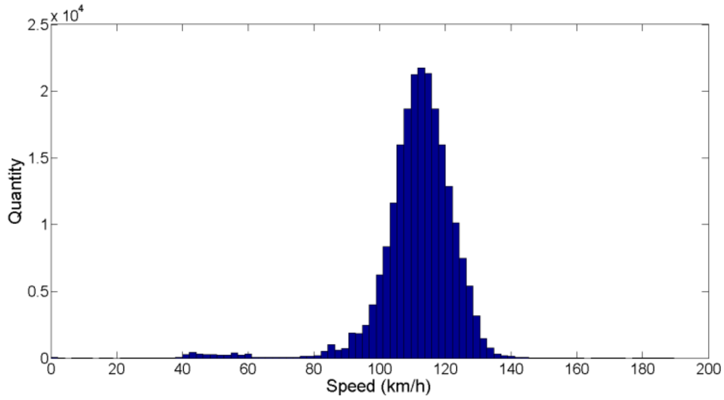


Fig. 3.
Histogram of traffic speed from D1 motorway

4. Experimental results

Our algorithm was implemented in Matlab environment and utilized basic parallelization to accelerate the computation. From the performance perspective, the only problematic part is the learning of parameters which can easily take tens of minutes. However, given enough historical data, it is not necessary to frequently update the model. The computation of prediction with trained model takes only tens of seconds.
The algorithm was tested on data coming from Czech D1 motorway from the period of 1.9.2014 to 30.11.2014. We have chosen 3 consecutive sections from 180th to 195th km in the direction of Brno (i.e. graph structure was the same as in Fig. 2). Traffic speeds from both ASIM data and FCD were discretized according to the scheme presented in the previous part and had 18 and 26 states respectively. Each of these section contained ASIM sensor. Two of these were used for learning and the values from the last one were not included in training set (i.e. remained unobserved). It was, however, used for result verification. We have used data from September to October for training and data from November for evaluation. Root Mean Square Error (RMSE) was chosen as a measure for quality of the prediction. All three learned models were tested and gave similar results. For the sake of space, we only present results from the first one. We have run online prediction predicting the state of the traffic speed in these three segments 5 minutes ahead for the duration of one hour. Results from one of these predictions can be seen in Fig. 4, 5 and 6.

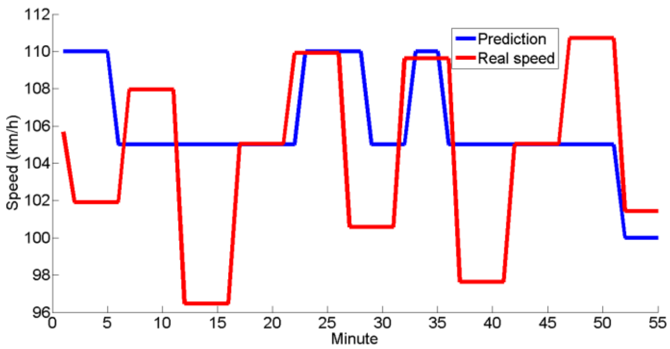


Fig. 4.
Traffic speed prediction for the first segment

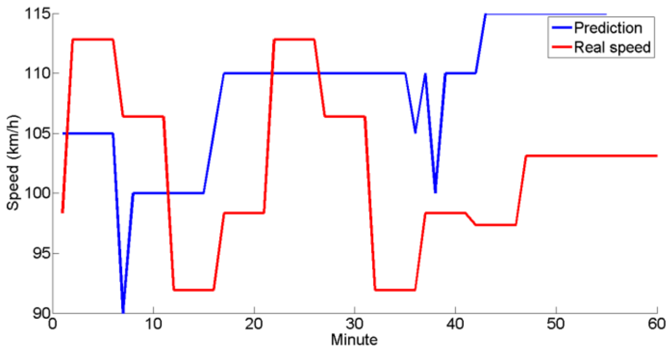


Fig. 5.
Traffic speed prediction for the second segment

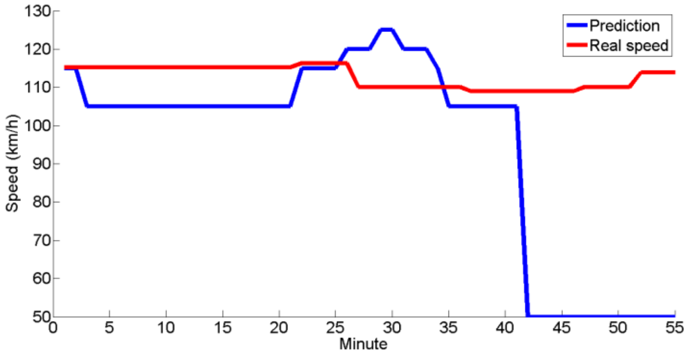


Fig. 6.
Traffic speed prediction for the third segment

The predictions for the first segment (Fig. 4) have RMSE of 5.1258, for the second segment (Fig. 5) RMSE of 10.0327 and for the third which was the one without the ASIM in learning set (Fig. 6) RMSE of 31.5727. In terms of RMSE mean value from all predictions, the confidence interval for the first segment is $< 8.0441, 8.3864 >$, for the second is $< 10.7243, 11.6859 >$ and for the third is $< 14.4149, 15.5572 >$. From these results it is clear, that presence of unobserved variable seriously degrades quality of the results, which is otherwise comparable to results of other contemporary works (Jiang and Fei, 2015). This fact restricts usability of this algorithm to areas with both ASIM and FCD data. However, overcoming of this problem will be main topic of the future research.

5. Conclusion

In this article, an approach to traffic speed prediction on motorways based on dynamic Bayesian network was presented. In proposed algorithm, ASIM sensors and FCD were used as valuable data sources. Both accuracy of the ASIM data and availability of the floating car data were utilized.
In comparison with other approaches like (Jiang and Fei, 2015), our algorithm performed comparably in case of complete data. In case of missing ASIM sensor, quality of results was seriously degraded, but in average stayed within reasonable limits. Main advantage of our algorithm is, that in contrast with many other algorithms, it works with real world traffic data from both FCD and stationary sensors and utilizes advantages of both of them, while, to some extent, overcoming their disadvantages. Results have proven, that our model describes the behaviour of traffic on motorways reasonably well.
This algorithm, however, can still utilize some improvements. The most important improvement will be to resolve the issue of slow and, in case of unobserved data, imperfect learning. This task will be addressed by parallelization of EM algorithm and by experiments with utilization of other optimization algorithms within EM algorithm.

Acknowledgements

This work was supported by The Ministry of Education, Youth and Sports from the National Programme of Sustainability (NPU II) project 'IT4Innovations excellence in science - LQ1602', and supported by 'Transport Systems Development Centre' co-financed by Technology Agency of the Czech Republic (reg. no. TE01020155) and co-financed by the internal grant agency of VŠB Technical University of Ostrava, Czech Republic, under the project no. SP2016/166 'HPC Usage for Analysis of Uncertain Time Series II'.

References

Boyen, X.; Koller, D. 1998. Tractable Inference for Complex Stochastic Processes. In *Proceedings of the Fourteenth Annual Conference on Uncertainty in Artificial Intelligence (UAI-98)*, 33-42.
Castillo, E.; Menendez, J. M.; Sanchez-Cambronero, S. 2008. Predicting traffic flow using Bayesian networks, *Transportation Research Part B*, 42(5): 482-509.
Herring, R.; Hofleitner, A.; Abbeel, P.; Bayen, A. 2010. Estimating arterial traffic conditions using sparse probe data. In *Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference*, 929-936.
Hoong, P. K.; Tan, I. K. T.; Chien, O. K.; Ting, C. Y. 2012. Road traffic prediction using Bayesian networks. In *Proceedings of the International Conference Wireless Communications and Applications (ICWCA 2012), IET*, 1-5.
Huang, M.-L. 2015. Intersection traffic flow forecasting based on v-gsvr with a new hybrid evolutionary algorithm, *Neurocomputing*, 147: 343-349.
Jiang, B.; Fei, Y. 2015. Traffic and vehicle speed prediction with neural network and hidden Markov model in vehicular networks. In *Proceedings of the Symposium 2015 IEEE Intelligent Vehicles*, 1083-1087.

Shiliang, S.; Changshui, Z.; Yi, Z. 2005. Traffic Flow Forecasting Using a Spatio-temporal Bayesian Network Predictor, *Artificial Neural Networks: Formal Models and Their Applications – ICANN 2005, Lecture Notes in Computer Science*, 3697: 273-278.

Tang, T.-Q.; Caccetta, L.; Wu, Y.-H; Huan, H.-J; Yang, X.-B. 2014. A macro model for traffic flow on road networks with varying road conditions, *Journal of Advanced Transportation*, 48(4): 304-317.

Wang, X.; Peng, L.; Chi, T.; Li, M.; Yao, X.; Shao, J. 2015. A Hidden Markov Model for Urban-Scale Traffic Estimation Using Floating Car Data, *PLoS ONE*, 10: 12.

Wang, Y.; Kuang, Lan. 2015. A Traffic Prediction Method based on Complex Event Processing and Adaptive Bayesian Networks. In *Proceedings of the The 2015 International Academic Research Conference*.

Zhu, Z.; Peng, B., Xiong, C.; Zhang, L. 2016. Short-term traffic flow prediction with linear conditional Gaussian Bayesian network, *Journal of Advanced Transportation*, 50(6): 1111-1123.

UTILIZATION OF TRAIN ROUTES IN RELATION TO THE IMPLEMENTATION OF PERIODIC TIMETABLE

Přemysl Šrámek[1], Tatiana Molková[2]
[1,2] *University of Pardubice, Jan Perner Transport Faculty, Department of Transport Technology and Control, Pardubice, Czech Republic*

Abstract: This paper deals with the problem of railway line capacity in terms of periodic timetable implementation. Periodic timetable is often required by customers like use friendly variant in passenger transport or due to guaranteed delivery time in freight transport. If it is not possible to construct new lines or tracks and it is not possible to realize any reconstruction measures, it will be appropriate to implement some operational measure, e. g. to improve the utilization of train paths, resp. to determine the influence of periodicity of a timetable to the railway line capacity. Nowadays, according to increase in the number of international freight expresses on corridors, it must be implemented sufficient amount of train routes for these trains into a timetable. Namely, it is chosen an area in the Czech Republic, which is composed of different types of railway lines, among others also of overlapping section of Rail Freight Corridors RFC 7 and 9. It is calculated the capacity consumption by UIC 406 leaflet in relation to the periodicity rate. For calculation is used the simulation tool SimuT, which is also used by Czech Railway Infrastructure Administration for capacity evaluation. By simulation tool there are input random entry delay based on exponential probability distribution. For every simulation screenplay is then counted the average delay increment – this capacity indicator is most important to evaluate the utilization of train routes in terms of quality and quantity. There are created different variants of timetables with variant periodicity rate. Every screenplay consists of 365 simulation runs.

Keywords: line capacity, periodic timetable, SimuT, train routes.

1. Introduction

Nowadays, to be attractive and competitive railway transport must fulfil many requirements. Passengers require comfortable and fast travelling, carriers require modern, fast, reliable and relatively cheap infrastructure with allocable capacity and infrastructure managers require some time for infrastructure repairs. To repair, modernize and maintain the railway infrastructure needs the infrastructure manager a lot of sources, which he can gain by infrastructure operation (or by government subsidies). The more train paths for infrastructure manager, the more sources for repairing and modernizing. Unfortunately for infrastructure manager is not possible to easily increase the quantity of train paths due to carriers and passengers requirements, which emphasizes especially the quality of train operation. To the quality folder it can be included the periodic timetables construction, periodic freight train paths in network or stability of timetables. Therefore is necessary to find the optimal utilization of train routes, related to the implementation of periodic timetable (optimal combination of quality and quantity). The aim is to reach sufficient amount of train routes (in comparison with the timetable 2016) with sufficient timetable stability, without overloading capacity. The goal is to find out the relation between timetable stability and timetable periodicity rate.

2. Data and methods

There are mentioned some information about chosen closed railway network, about European Freight Corridors RFC, about leaflet UIC 406 and about the simulation method (simulation tool SimuT with average delay increment (ADI) calculation).

2.1. Closed railway network

It must be differentiated an open network local stability and closed network total stability. In this case is counted for closed railway network the total stability, it means a system is totally stable in the case of input delay eliminating in the defined time (all processes are running in the frame of closed network) (Hansen, Albrecht, 2008).
It was chosen a closed railway network in the Czech Republic consisting of various lines (different number of tracks, different security equipment e. t. c.), among others of overlapping section of Rail Freight Corridors RFC 7 and RFC 9 (namely section Kolín – Choceň). The whole chosen closed railway network is yellow marked on Figure 1.

[1] Corresponding author: st24539@student.upce.cz

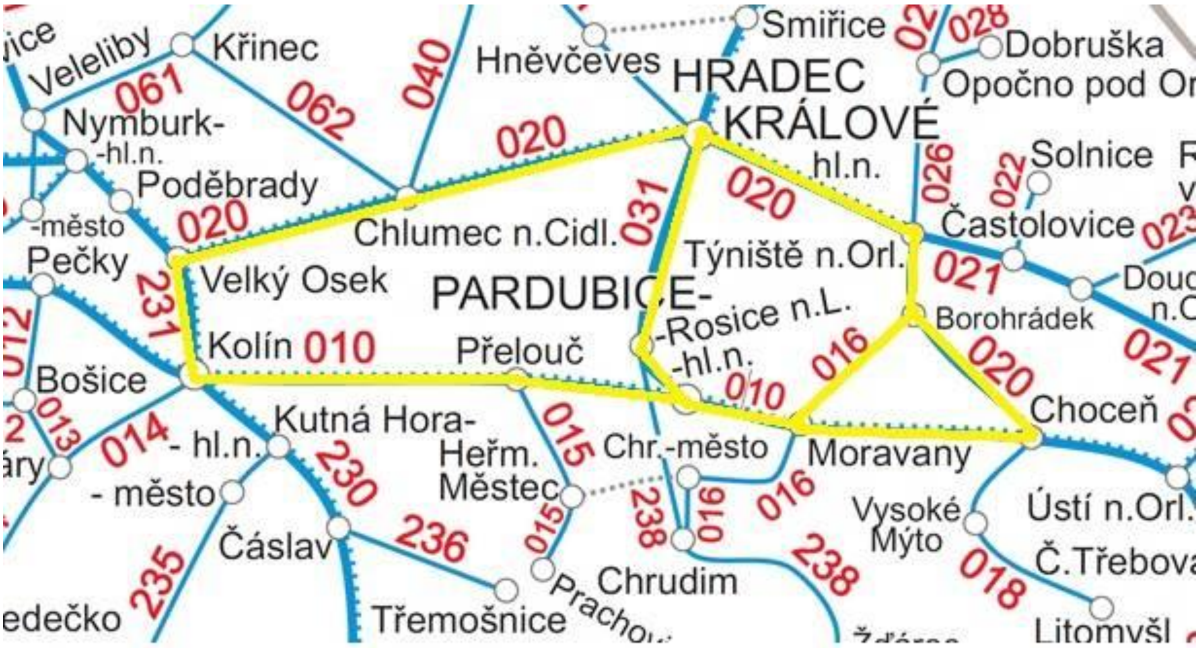


Fig. 1.
The chosen closed railway network
Source: Czech Railway Infrastructure Administration (CRIA)

The line 010 is the overlapping section of RFC 7 and RFC 9, double track, electrified, equipped with ETCS Level 2. The line 020 is single track, electrified and it serves as diversion route for the corridor line 010 in the case of exceptionalities. The line 031 is single track with one double track section with assumption of building double track line in the whole length of the line. It connects 2 county seats Pardubice and Hradec Králové (HK), which have in common 250 000 habitants (with agglomerations). The line 231 is called "Right Bank Line", while it is located on the right bank of the river Elbe. This line is double track, electrified and on this line turns a great amount of freight expresses from the line 010, while the line 231 heads to Germany avoiding Prague. The line 016 is single track, not electrified with operation consisted of stop passenger trains and handling freight trains, only (SŽDC, s. o., 2016).

2.2. Rail Freight Corridors (RFC)

On the basis of the European Parliament and the EU Council no. 913/2010 for competitive freight and no. 1316/2013, which is created the Connecting Europe Facility (CEF), is the gradual establishment of rail freight corridors RFC (Rail Freight Corridors). The main aim of the operation of these corridors is to strengthen the competitiveness of railways synergies between rail systems and harmonization of allocation interstate freight routes by national infrastructure managers (Čech, Šlachtová, 2015).
Czech Republic, respectively Czech Railway Infrastructure Administration (CRIA), as the infrastructure manager and allocator of capacity, is a member of RFC 5 (Baltic - Adriatic), RFC 7 (Orient / East-Mediterranean), RFC 8 (North Sea - Baltic) and RFC 9 (Czechoslovak corridor). Each corridor is operated on the basis of the Corridor information document (CID); each corridor has a single point of contact (C OSS) and allows carriers to apply international prearranged train paths facilitated freight via C-OSS. The request must be filed by information system RNE PCS and must include the cross-border section (Čech, Šlachtová, 2015).
RFC 7 - the Orient corridor runs from Central Europe to Eastern- and Southern-Europe connecting 7 member states - Czech Republic, Austria, Slovak Republic, Hungary, Romania, Bulgaria and Greece. The total length of main lines is approx. 3 900 km and the length of alternative and connecting lines is almost 2 500 km altogether (RFC 7 Orient Corridor, 2015). RFC 9 - the Czech-Slovak Rail Freight Corridor (CS CORRIDOR) runs from Prague to Čierna nad Tisou (Slovak-Ukrainian border) connecting 2 member states - Czech Republic and Slovak Republic. The total length of main lines is 972 km and the length of alternative and connecting lines is 276 km altogether (RFC 9 CS Corridor, 2013).
In capacity analysis, published in Implementation plan of RFC7, there are found lines with capacity utilization higher than 90 %. The longest sections with this high capacity utilization are situated in the Czech Republic, namely sections Poříčany - Pardubice (65 km) and Choceň - Česká Třebová (25 km) (RFC 7 Orient Corridor, 2015).

2.3. The UIC 406 leaflet

The UIC 406 leaflet, completely overhauled in June 2013, is one of the most important documents about the capacity calculation. There is published the approach to calculate capacity consumption by compressing a timetable and to evaluate the number of possible train path to a node, line or corridor. Corridor is in the UIC 406 defined as the main international and national connection and thus usually stretches over several hundred kilometres. Corridors may overlap with one another. On the basis of UIC 406 leaflet there are counted capacity indicators Occupancy Time Rate, Additional Time Rate and Capacity Consumption (UIC, 2013).

2.4. The simulation method

In this part is said something about the simulation method. In the chosen closed railway network there are a total amount of 29 railway stations, in which it is possible overtaking trains (double track line) or crossing trains (single track line). The amount of trains on each line is displayed in the Table 1. It is displayed for the present operation - timetable 2016 (TT 2016), constructed periodic timetable (PTT) and constructed periodic timetable with periodic freight train paths (PFTP, rescheduling of freight expresses). The upper number in the cell is total amount of trains on the line and bottom numbers is the amount of trains of: long distance passenger transport/regional passenger transport/freight transport. The letter X means the train category isn't operated on a line. The shortcut HK means Hradec Králové hl. n., the shortcut VO then Velký Osek station.

Table 1
The amount of trains

Line/Timetable	TT 2016	PTT	PFTP
Kolín – Choceň	384 171/62/151	336 104/83/149	336 104/83/149
Choceň – HK – VO	174 30/106/38	108 50/40/18	114 50/40/24
Pardubice – HK	137 19/105/13	179 118/40/21	179 118/40/21
Kolín – VO	213 16/78/119	221 38/40/143	221 38/40/143
Moravany – Borohrádek	48 X/42/6	57 X/38/19	57 X/38/19
Total amount of trains (whole network)	956 236/393/327	901 310/241/350	907 310/241/356

Source: Author

For simulation was used simulation tool SimuT, developed by Pavel Krýže, PhD. from CRIA.
The simulation tool SimuT is developed in Visual Basic, therefore it can run on every PC with Microsoft Office. It has to be input the option of a simulation, then railway stations and their shortcuts, station tracks for each railway station, line tracks, connection of station and line tracks, length of interstation departments and amount of line departments, type of train for priority, type of train for each number of a train and the path of each train. The simulation program SimuT can put new paths in a daily timetable with the solution for arisen path conflicts (Šrámek, Molková, 2016).
It was created the daily timetable, the passenger transport trains were concentrated especially from 6 am to 23 pm. Within the simulation program was established the average delay increment (ADI). The average delay increment was calculated by dividing the difference between total output and total input delay and the total number of trains. This indicator was calculated as an ongoing basis for each simulation run, so the total for the entire graph (all simulation runs). The indicator was also calculated for different types of transport, i.e. for long-distance passenger transport, regional passenger transport and freight transport (Šrámek, Molková, 2016). On the basis of occupancy time counted by SimuT were counted by author UIC 406 capacity indicators Occupancy Time Rate (K), Additional Time Rate (R_T) and Capacity Consumption (C).
Three variants were created in SimuT. The first variant covers current railway operation in the Czech Republic. In the second variant there was created a periodic timetable on the basis of keeping up similar amount of trains of each train category, but with periodic routing for each train category. The third variant added to the periodic timetable optimization of freight train paths in network through path rescheduling via bottlenecks (Drábek, 2013). For timetable stability evaluation in relation with periodicity it is counted the periodicity rate – percentage of trains in PTT or PFTP and the whole number of trains.
It must be said the amount of trains in each train category is different for each variant. The whole amount of trains in TT 2016 is higher than in PTT or PFTP, but the heterogeneity is different. For SimuT one train means one train number. In PTT and PFTP there is then less amount of train numbers, but one train number covers on average longer distance in PTT or PFTP because of creating of comprehensive train routes.
As part of the simulation was set for all simulation runs random entry delay based on the exponential probability distribution. There were solved conflicts of station tracks, freight trains were allowed to ride before their schedule time (in the case of free capacity). For each variant was made a total of 365 runs of simulation (for a daily timetable) (Šrámek, Molková, 2016).

3. Results and Discussion

In the simulation there was gained timetable stability indicators – average delay increment for all trains (ADI), average delay increment for long distance passenger transport (ADIL), average delay increment for regional passenger transport (ADIR) and average delay increment for freight transport (ADIF). Total delay for whole network is the dot product of train number matrix and ADI matrix. ADI for whole net is then total delay divided by total amount of trains. These most important timetable stability indicators are in the tables yellow marked. Table 2 is made for timetable 2016, Table 3 for periodic timetable and Table 4 for periodic timetable with periodic freight train paths (rescheduling via bottlenecks).

Table 2
ADI and periodicity rate in timetable 2016

Line/Indicator	ADI (min/train)	ADIL (min/train)	ADIR (min/train)	ADIF (min/train)	Periodicity (%)
Kolín - Choceň	1.05	2.77	- 0.01	- 0.46	47.40
Choceň – HK – VO	- 1.26	- 0.60	- 1.23	- 1.88	44.83
Pardubice hl. n. – HK hl. n.	- 0.20	- 0.61	- 0.25	0.78	38.69
Kolín – VO	0.27	- 0.01	- 0.04	0.52	37.09
Moravany - Borohrádek	- 0.29	X	- 0.17	- 1.16	60.42
Total delay (min)/periodicity (%)	200.15	443.92	-167.51	-75.84	44.04
ADI for whole net (min/train)	0.21	1.88	-0.43	-0.23	

Source: Author

Table 3
ADI and periodicity rate in periodic timetable

Line/Indicator	ADI (min/train)	ADIL (min/train)	ADIR (min/train)	ADIF (min/train)	Periodicity (%)
Kolín - Choceň	- 1.03	3.30	- 1.72	- 3.67	100.00
Choceň – HK – VO	- 2.21	- 0.29	- 1.81	- 8.46	86.11
Pardubice hl. n. – HK hl. n.	0.76	- 0.12	- 0.57	8.28	100.00
Kolín – VO	0.26	0.07	0.32	0.30	100.00
Moravany - Borohrádek	- 0.88	X	- 0.60	- 1.43	100.00
Total delay (min)/periodicity (%)	-441.42	317.20	-247.96	-509.50	98.34
ADI for whole net (min/train)	-0.49	1.02	-1.03	-1.46	

Source: Author

Table 4
ADI and periodicity rate in periodic timetable with periodic freight train paths

Line/Indicator	ADI (min/train)	ADIL (min/train)	ADIR (min/train)	ADIF (min/train)	Periodicity (%)
Kolín - Choceň	-1.03	3.30	-1.72	-3.67	100.00
Choceň – HK – VO	-3.14	0.02	-1.66	-12.20	88.60
Pardubice hl. n. – HK hl. n.	0.76	-0.12	-0.57	8.28	100.00
Kolín – VO	0.26	0.07	0.32	0.30	100.00
Moravany - Borohrádek	-0.88	X	-0.60	-1.43	100.00
Total delay (min)/periodicity (%)	-560.70	332.70	-241.96	-650.02	98.57
ADI for whole net (min/train)	-0.62	1.07	-1.00	-1.83	

Source: Author

With the increasing periodicity are getting the total delay and ADI for whole net lower. In the periodic timetable are in comparison with timetable 2016 all indicators better, in the periodic timetable with periodic freight train paths is much better (lower) ADIF, but a bit worse ADIL and ADIR (in comparison with periodic timetable). It is the price for effective routing of freight expresses, but the effect for whole network is positive (lower total delay and ADI for whole net). Visually are the tables compared on Figure 2 (total delay).

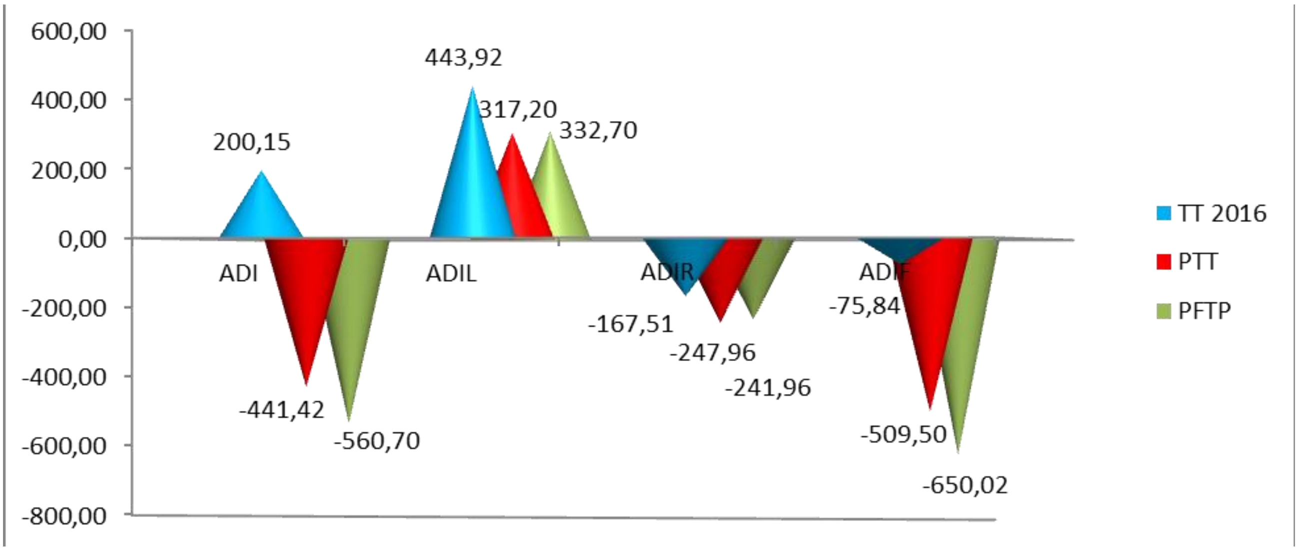


Fig. 2.
Comparison of total delay
Source: Author

To be sure, are in Table 5 displayed UIC 406 capacity indicators for sections with higher capacity utilization (higher occupancy time).

Table 5
UIC 406 capacity indicators for chosen sections

Interstation department	K (%)	R_T (%)	C (%)
Pardubice hl. n. – Přelouč, TT 2016	55.94	78.77	93.42
Pardubice hl. n. – Přelouč, PTT	60.10	66.38	100.37
Pardubice hl. n. – Přelouč, PFTP	60.10	66.38	100.37
Třebechovice – HK – Sl., TT 2016	39.55	152.85	66.05
Třebechovice – HK – Sl., PTT	58.19	71.84	97.18
Třebechovice – HK – Sl., PFTP	64.27	55.59	107.33
Pardubice – Rosice – Stéblová, TT 2016	35.63	180.70	59.49
Pardubice – Rosice – Stéblová, PTT	69.10	44.72	115.39
Pardubice – Rosice – Stéblová, PFTP	69.10	44.72	115.39

Source: Author

With the increasing periodicity are the UIC 406 capacity indicators raising and the infrastructure seems to be more overloaded. It is very interesting with increasing periodicity is timetable on a closed railway network more stable, although some interstation departments are overloaded. It is possible in case of periodic timetable the infrastructure utilization could be in a few sections very high (up to the overloading), but if train routes are effectively made and bundled, it could be reached very high timetable stability. It is true in PTT and PFTP there are less trains than in TT 2016, but indicators ADI, ADIL, ADIR and ADIF are counted for one train, so their predictive value is appropriate.

4. Conclusion

With periodic timetable implementation could be reached very good timetable stability, although some interstation departments could be overloaded. Generally, in PTT and PFTP was routed less amount of trains, but the structure of trains has changed – there were strengthened segments of long distance passenger trains and freight trains, regional passenger trains were realized in less amount, but with preservation of commitment to public service (transfers from long distance passenger trains).

Optimal utilization of train routes is that one with sufficient timetable stability, sufficient quality for customers and sufficient quantity for infrastructure manager. Through PTT implementation is reachable very good timetable stability and high quality (use friendly network connections), the quantity is then lower, unfortunately, but sufficient for generation sources to maintain and modernize the infrastructure. At first, it is the turn of infrastructure manager to modernize interstation departments with overloaded capacity – then could be reached higher quantity in good quality. Through PFTP implementation could be satisfied the needs of freight carriers, optimized the network indicators and fulfilled requirements of prearranged train paths on RFC.

Acknowledgements

This article is supported by Students grant competition of University of Pardubice No. SGS_2016_008.

References

Čech, R.; Šlachtová, M. 2015. Železniční nákladní koridory RFC, *Železniční magazín Czech Raildays,* 8-9.
Drábek, M. 2013. *Periodic Freight Train Paths in Network*, FD ČVUT, Czech Republic.
Hansen, I. A.; Albrecht, T. 2008. *Railway timetable & traffic*, Eurailpress, Hamburg, Germany.
International union of railways (UIC) 2013. *UIC CODE 406, 2nd edition*,UIC, Paris, France.
RFC 7 Orient Corridor. 2015. Implementation plan of rail freight corridor 7 Orient Corridor. Available from Internet: <http://www.rfc7.eu>.
RFC 9 CS Corridor. 2013. Implementation plan of rail freight corridor 9. Available from Internet: <http://www.szdc.cz>.
SŽDC, s. o. 2016. GVD 2016. Portál provozování dráhy. Available from Internet: <http://provoz.szdc.cz>.
SŽDC, s. o. 2016. Staniční řády vybraných ŽST. Portál provozování dráhy. Available from Internet: <http://provoz.szdc.cz>.
Šrámek, P.; Molková, T. 2016. The priority of international freight expresses in the overlapping section of RFC 7 and RFC 9 Kolín - Česká Třebová. In *Proceedings of the IRICON 2016,* 31–32.

POSSIBILITIES TO EVALUATION RAILWAY TRACKS IN CONDITIONS OF THE SLOVAK RAILWAYS

Juraj Čamaj[1], Jaroslav Mašek[2], Anna Dolinayová[3], Jozef Daniš[4]
[1,2,3,4] *University of Žilina, The Faculty of Operation and Economics of Transport and Communications, Department of Railway Transport, Univerzitna 8215/1, 010 26 Žilina, Slovakia*

Abstract: The railway transport is one of the important sectors of the national economy, which substantially affects the development and growth of the economic level in every region. The European Commission and government of European countries declared in the documents aim to shift part of the volume of freight transport from road to rail. Building and reconstruction of railway network requires the comprehensive view of everyone infrastructure project. The paper is focused to the evaluation railway tracks in the Slovakia by using Multi-Criteria method. Evaluation of railway tracks has important impacts for the assessment of the technical equipment investment, important impact for time discreet train formation and for the allocation of marshalling yards. Transport model for evaluation the railway tracks used the marshalling yards like the centers for the operation assigned catchment area. This model is one of the effective ways to meet the development strategy of the European Community's railways. By applying this model in practice, a transport company can guarantee a higher quality of service and then expect an increase of performance. The model is also applicable to other rail networks. This model supplements a theoretical problem of train formation problem of new ways of looking at evaluation of factors affecting the organization of wagon flows. This transfer should occur in particular in order to decrease the environmental pollution, reducing the number of traffic accidents with fatal consequences and elimination of congestion on the road network in areas of large cities.

Keywords: evaluation model, wagon flow, quality of the services.

1. Introduction

The railway transport is one of the important sectors of the national economy, which substantially affects the development and growth of the economic level in every region. Building and reconstruction of railway network requires the comprehensive view of individual infrastructure projects (Camaj, 2008). The European Commission and government of European countries declared in the documents aim to shift part of the volume of freight transport from road to rail. This transfer should occur in particular in order to lessen environmental pollution, reducing the number of traffic accidents with fatal consequences and elimination of congestion on the road network in areas of large cities.

2. Basic description of the transport network

(From the perspective of modeling the transport network composed of operating control points and sections, which can be interpreted as vertices and edges oriented twice valuation multigraph (Camaj, 2008).
Applying the methods of graph theory is the appropriate mathematical apparatus for description, analysis and synthesis of transport networks (Zitricky, 2015). Formal transport network is determined by a set of peaks (P) and edges (E) with the double-valued (permeability and length):

$$S = (P, E, p, l) \tag{1}$$

The permeability (one-way) is determined by the number of sets that can enter into the section per unit time. Very important is the determination of edge weight. Weight of edges can be expressed not only in units of length (km), as well as e.g. average time (minutes or hours) required for its passage. In connection with the creation of a model railway infrastructure can be very suitable to be difficult formulation the optimality criterion. A number of practical problems are defined as multi-criteria tasks.

3. Methods of multi-criteria analysis

Analytical methods generally constitute a set of rules and procedures applied, which can come to a proper assessment of the subject that is for adopting the best solution. The current mathematical system offers a wide range methods of decisions. Analytical methods can be divided into three groups on empirical, heuristic and exact methods (Dolinayova, 2015).
An empirical methods are based on experience, intuition and subjectivity. These methods can be divided into empirical-intuitive ("trials and errors"), empirical-analytical (analysis replaces intuition), Expert (Delphi method/expert opinions, brainstorming, brain writing, the method of scenarios).
Heuristic methods used the advantages of empirical and statistical methods. They are based on common sense and logic. These methods include the decision table, decision tree, decision analysis and preference theory (if 60% chance that the decision is correct, it should accept the decision maker (Křupka, 2012).
An exact methods are based on scientific analysis and decision-making designed to solve situations that are repeated, and where relationships between elements are expressed quantitatively. This group of methods include (Dolinayova,

[1] Corresponding author: juraj.camaj@fpedas.uniza.sk

2016): methods of Mathematical Statistics (probability theory, correlation analysis, time series analysis), methods of mathematical analysis and linear algebra (differential calculus, extrapolation, matrix), Methods of Operational Analysis (Mathematical Methods in Economics, structural analysis, network analysis, queuing models and so on.

Comprehensive evaluation process is carried out in increasingly complex dynamic conditions. Therefore, it is necessary to choose the appropriate method of their choice, which will take into account several criteria:

- **The point evaluation method** is a system of scoring scale (e.g. 5-point scales). Using the criteria they are often characterized by different terms (one is positive, the other negative), so when evaluating a number of indicators is important in their common core. If this condition is met, it will be according to the degree of importance attached to individual criteria individually and weight of point scores (Fotr, 1988).
- **Evaluative index method** is used when it is necessary to concentrate all the criteria to one decision to one indicator, where:
  - Criteria have different in terms of quantification and randomness.
  - Criteria are from different areas of commercial, production, distribution and so on.
  - Criteria have different importance given the objective analysis (Fotr, 1988)
- **Decision Matrix Method (DMM)** is considered as the basic method of multi-criteria decision making. It may have more variants. One variant consists in the evaluation weight (importance) of the request point scale from 1 to 10 such that the stage 1 is assigned the smallest weight and the maximum weight of 10 degree. The same scale was also assessed the fact as each alternative meet the selected criteria, ie. to "1" - did not match up to "10" - meets perfect. (Křupka, 2012) For the final criterion for the decision is then selects the greatest weighted sum (sum of the product of the extent to evaluation criteria and their weights). Its advantages are simplicity and relatively low process time-consuming, the disadvantages are the high proportion of subjectivity in the valuation criteria and weighting in the assessment of how individual variations meet the selected criteria
- **Forced Decision Matrix Method** – partially eliminates the disadvantages of DMM. Weights of individual criteria and an evaluation of options to meet individual criteria are determined so pairwise comparison. This means that when comparing two criteria is more important (to decide important) criterion marked "1" less important criterion of "0". Similarly, when evaluating how two variants meet the selected criteria of evaluation are satisfactory options better, rated "1" variant and rated worse "0" (Křupka, 2012). The final evaluation of alternatives or weighting of criteria so we get the rating "normal", ie. we demand that the sum of all respectively the balance was equal to 1. FDMM advantage is the relative simplicity of the procedure and the elimination of subjectivity in determining the weights and impact criteria as they are more accurately identified. The disadvantages include relatively large differences in the evaluation of options and criteria, even if they differ only slightly, and in determining the weight criteria or evaluation of alternatives equals "0", not the overall assessment of any impact (Fotr, 1988).
- **The competence index of supplier** is a tool designed to distinguish the weighting of each criteria from the perspective of the customer. The basic formula for the calculation of the relationship:

$$CIS = \sum_{i=1}^{n} HK_i.w_i \tag{2}$$

where:
n – number of criteria,
w_i – weight of each criteria, where $\sum_{i=1}^{n} w_i = 1$
CIS – competence index of supplier
R_i – rating of *i-th* criterion, where is valid: $R_i = f(R_{ir}, R_{iopt})$
R_{ir} – real rating of *i-th* criterion
R_{iopt} – designated optimal rating for *i-th* criterion.

In practice, the evaluation criteria for *Ri* is calculated as the ratio of optimal and fair value of the criteria. It is generally accepted rule is that if the optimum minimum value, expressed, and this is optimum in the calculation of the numerator of each formula. Conversely, if the optimum expressed as a maximum, then in calculating the denominator of the formula. In calculating the optimum values by the extremes (minimum and maximum), then the optimum value of 1. Otherwise the value of CIS is ideal as high as possible value of the index (Fotr, 1988).

• **Analytic Hierarchy Process (AHP**). This method creates DR. Thomas Saaty in the 70s of the last century. It is a decision-making method for determining priority criteria when it must be compared more criteria. Generally, the hierarchy of three levels: the objective criteria and alternatives (Křupka, 2012). This method is still the most valuable and useful in the world. The method allows the best choice based on preference. The advantage of the method lies not only in finding the optimal result, but also allows you to view and clear intermediary elements that contribute most to the outcome (Křupka, 2012). Its disadvantage is the need to make numerous comparisons.

• **Preference Ranking Organisation Method for Enrichment Evaluations** – **PROMETHEE** allows the user to directly use simple multi-criteria table. Instead of having to undertake large number of comparisons, the decision maker defines only its own scale of measurement (without limitation), to determine their priorities and their preferences for each criterion. The advantage of the method **PROMETHEE** that enables fast the sensitivity of the visual form and calculate the robustness of the current classification for each criterion (Křupka, 2012).

4. The individual criteria of railway tracks

The rail network comprises railway lines, which consists of track sections. The assessment parameters tracks can be based on their characteristics divided according to several criteria.

4.1. Infrastructure fee

The fee for the use of the railway infrastructure in the Slovak Republic is paid by the transport operator to the railway for the use of the railway lines. The total amount for access to the railway infrastructure is defined as:

$$U_C = U_{mp} + U_{tp} \tag{3}$$

The calculation of the total payment for a minimal access packet for the train will be determined as the charge summary for capacity ordering and allocation, charge for traffic management and organization and charge for securing transport ability according to the pattern (Dolinayová, 2016):

$$U_{mp} = \sum_{i=1}^{6} U_{1i} * L_i + \sum_{i=1}^{6} U_{2i} * L_i + \frac{1}{1000} * \sum_{i=1}^{6} U_{3i} * Q_i * L_i * k_e \tag{4}$$

where:
Ump - total reimbursement for the use of the railway infrastructure,
U1i - maximum reimbursement for ordering and allocating capacity
U2i - maximum reimbursement for managing and organizing transport
U3i - maximum reimbursement for ensuring the operability of the railway infrastructure
Li - total track length of the competent category between single transport points in kilometers
Qi - total gross weight of the train rounded to the whole ton
ke - coefficient which takes into account the movement of the train with an active driving rail vehicle using diesel traction on electrified tracks, the size of this coefficient being 1.2. The coefficient for the other trains is 1.0.

The calculation for total payment for track access to service devices for freight trains consists of a charge for use of an electric feeding device, a charge for train assignment and it will be determined according to the pattern:

$$U_{tp} = \frac{1}{1000} * Q * L_e * U_e + \sum_{j=A}^{D} P_{Pj} * U_{Nj} \tag{5}$$

where:
Q - total gross weight of train harnessed on electrified track rounded to the whole ton
Le - length of electrified stretch utilized in kilometers
Ue - maximum reimbursement in €/thousands of gross ton kilometers for electrical supply used
PPj - number of train accesses according to the respective category of transport points for freight transport trains
UNj - maximum reimbursement in € for access of freight transport trains. (Dolinayová, 2016)

4.2. The Traction energy

By type of traction we distinguish in Slovakia on track:
- electrified,
- non electrified.

Electrified tracks can be split according to the type of current and frequency to:
- DC electrified lines with the traction voltage of 3 kV,
- AC electrified lines with 50 Hz frequency and voltage 25 kV,
- AC electrified lines with 16.7 Hz frequency and voltage 15 kV.

4.3. The track class

The maximum permissible axle load is dependent on the carrying capacity of the railway infrastructure and bridge. Axle weight is given in tones and is calculated by dividing the gross weight of wagons, i.e. the sum of its own weight and the weight of the wagon load by number of axles. If the data at the axle load is not any indicator that mentioned axle load is part of the maximum allowable (Mašek, 2015). UIC track all sorts of weight per unit length of vehicles in classes A, B1, B2, C2, C3, C4, D2, D3, D4. The markings with capital letters (A, B, C, D) account for the highest permitted axle load indication and the arabic numbers (1, 2, 3, 4) corresponds to the highest permitted gross vehicle weight per unit length. Overview categories of track classes is in Table 1.

Table 1
The track classes and their maximal loading

The track class	The maximum permissible axle load	The maximum permissible weight of the meter wagon
A	16.0 t	5.0 tpm
B 1	18.0 t	5.0 tpm
B 2	18.0 t	6.4 tpm
C 2	20.0 t	6.4 tpm
C 3	20.0 t	7.2 tpm
C 4	20.0 t	8.0 tpm
D 2	22.5 t	6.4 tpm
D 3	22.5 t	7.2 tpm
D 4	22.5 t	8.0 tpm

Source: Masek (2015)

4.4. The track construction

The rail line is composed of the railway substructure, railway superstructure and artificial structures.
The track substructure has a fundamental role to ensure a sufficiently stable connection of the rail body with the ground. The track superstructure is used for roadway rolling stock, leading them and carries. While also transmits power to the track substructure which arise while driving vehicles (Gašparík, 2015). The main task is keeping artificial construction of the railway line in places where they cannot be used alone embankments and indentations or their implementation would be much cost. The group of artificial structures we include retaining walls and restraint walls, tunnels, bridges, viaducts and culverts (Ližbetin, 2016).

4.5. The type of track interlocking system

The track interlocking system has a significant impact on the number of trains running in the interstation sections. Ensuring the movement of trains is carried out in accordance with existing traffic regulations depending on the type of interlocking system.
Track security devices are classified according to the level of security on device:

- 1st. category (train announcing points) the main signaling devices are independent by departures of trains and also by interlocking systems in adjacent operating control points
- 2nd. category (semi-automatic track interlocking system). They provide dependency between adjacent operating control points. Operation of the control unit of section or departures signaling devices is dependent on train movements and requires the cooperation of the operator.
- 3rd. category (full automatic track interlocking system – automatic block). They mediate dependence between adjacent operating control points. Operation of the control unit of section signaling devices is automatic. The control unit is dependent on drive train and does not require action and servicing staff.

Table 2
The track interlocking systems

Automatic block	**Total**	**670 km**
unidirectional automatic block		129 km
bidirectional automatic block		541 km
Automatic signal box		**512** km
Semi-automatic block	**Total**	**762** km
relay semi-automatic block		624 km
signaling semi-automatic block		138 km
Track with telephone communication		**1 556** km

Source: Network statement ŽSR (2015)

4.6. The gradient conditions of track

On the track of the gradient is determined speed limit between the maximum track speed and running speed by:
- size of the slope or climb on the track,
- according to the type of train brake system and drive performance vehicle,
- according to braking distance with respect to prescribed provisions of infrastructure manager.

The biggest gradient is determined for each track individually. The ruling (decisive) gradient is one that can be designed in a straight section of the track (Kendra, 2016).
The track is proposed in the uniform gradient for the longest sections. Where possible, the route is guided as a constant resistance of track (effect of curvature on the track, where applicable, placed in the tunnel route). The longitudinal gradient of the track is proposed in view of smooth start and safe stopping of trains (Kendra, 2013).
The track gradient should be as small as possible. The gradient conditions at operating control points and hump track are designed in accordance with the relevant regulations for the design of railway stations. The length of the horizontal sections should be as far as possible provided that it does not deteriorate the construction and maintenance solutions in traffic routes (Dolinayová, 2016).

4.7. Number of line tracks

The line track, which connects two adjacent operating control points is continuous track of rail. Tracks can be split according to the number of tracks to the single-track lines (allow movement of trains with only one direction) and double-track lines or multi-track lines (allow movement of trains in both directions simultaneously by different track rail) (Zitrický, 2015). The main characteristics of the railway network managed by ŽSR (as of 18.11.2015) is in table 3.

Table 3
The length of track by gauge (in km)

Total construction length of tracks	**3 625.522**
Operated: (km)	3 579.978
• single tracks (km)	2 563.255
• double tracks (km)	1 016.723
• narrow gauge track (km)	46.201
• broad gauge tracks (km)	98.718
• normal gauge tracks (km)	3 435.059

Source: Network statement ŽSR (2015)

4.8. The type of structure gauge

The structure gauge (SG) is defined as the plane perpendicular to the axis of the line, whose axis is perpendicular to the line joining down from the top of the rails, which may not intervene any part of fixed building or any part of the line track. The structure gauge, also called the minimum clearance outline, is the minimum height and width of tunnels and bridges as well as the minimum height and width of the doors that allow a rail siding access into a warehouse. In addition, the term may apply to the minimum distance to railway platforms (passenger or freight), buildings, electrical equipment boxes, railway signal equipment, third rails or to supports for overhead catenaries or overhead lines from the track (Skrucany, 2015).
The loading gauge is to determine of spatial pattern that may interest expense on open wagons. On the Slovak railways are using the following gauge in the following breakdowns (Network statement ŽSR, 2015):
- SG 1 C – SM/ŽSR:.
- SG 1 - SM_E/ŽSR:
- the bridges SG,.
- the tunnel SG,
- on the reconstruction line of Slovak railways– SG B, C,
- the line for multimodal transport SG UIC GC.

4.9. The line speed

The line speed is defined as a permanent maximum speed limit on the particular line, which is indicated in the Route Book. In addition to the line speed we know the set speed, the speed of the train is determined by its timetable. In the professional standards established by the infrastructure manager on Slovak railways (ZSR) is the rail speed defined according to different types of train (Camaj, 2008). All speed levels at the Slovak Railway are in the table 4.

Table 4
The distribution of the various speed zones

The speed level	Track speed
SL 1	to 60 km/h
SL 2	60 – 90 km/h
SL 3	90 – 120 km/h
SL 4	120 – 160 km/h
SL 5	up to 160 km/h

Source: Network statement ŽSR (2015)

When considering the possibilities of railway transport and routes to take into account the following factors:
- vibration of wagons from inequality on the track,
- adhesion, which is a decreasing of speed,
- curvature - Vertical drop of outer belts in curves, the radius of curvature in the track browsing, the radius of curves into turnout,
- deformation of the rails due to the deformation waves
- deformation of the contact wire collector,
- sound barrier.

To satisfy human and social needs appears more and more to the fore the time factor, along with the quality of service becomes a decisive factor in transport (Gašparík, 2015). Modernization of railway transport focusing on the issue of higher speed as one of the fundamental problems of a technical and economic character (Ližbetin, 2016).

5. Methodology for comprehensive evaluation of railway lines

A methodology for rating of lines can serve as support for modeling direction of load in train formation problem. Methodological aspects consist in applying the procedures leading to determine the meaning indicator and also a partial assessment. This requires the determination of:
- weights of individual indicators
- partial evaluation of indicators.

To determine the weight of the indicators needs to be in two steps:
- determine the weight of each group of indicators,
- determine the weight of each indicator in the group.

Weights of individual groups of indicators and weights of individual indicators in the group is based on a numerical scale by 1 to 6 point. The assignment one point represents a group resp. indicator with little importance and assignment of 6 points represents a group of indicators, resp. indicator of crucial importance

5.1. Parameters for evaluation and their indicators

After processing of individual assessment parameters lines is in the next step should be to assign to these parameters of individual indicators. These indicators characterize the individual parameters. The structure of indicators are shown in table 5.

Table 5
Parameters for evaluation and their indicators

Parameters	**Indicators**	points	**Parameters**	**Indicators**	points
1.The infrastructure fee	Train	**6**	7.The gradient conditions	horizontal	**6**
	Transport quantum	**1**		to 5 ‰	**5**
	Distance covered	**4**		to 10‰	**4**
2. Railway gauge	Normal gauge	**6**		to 20‰	**2**
	Narrow gauge	**4**		up to 20‰	**1**
	Broad gauge	**1**	8.Number of line track	Single-line track	**1**
3.The type of traction	Electric traction	**6**		Multi-line track	**6**
	Without electric traction	**1**	9.Character of traffic	Passenger	**1**
4.The track class	A	**1**		Freight	**6**
	B	**2**		Mixed traffic	**5**
	C	**5**	10. The type of structure gauge	1 – SM/ŽSR	**5**
	D	**6**		1 - SM_E	**5**
5.The line construction (age of railway superstructure)	0 - 5 year	**6**		The bridges SG	**2**
	6 - 10 year	**5**		The tunnel SG	**1**
	11 - 15 year	**4**		Intermodal transport SG UIC GC	**4**
	16 - 20 year	**3**		Modernized lines ŽSR – SG B	**6**
	21 - 25 year	**2**	11. Maximum line speed	60 km/h	**1**
	Up to 25 year	**1**		100 km/h	**3**
6. Type of line interlocking system.	Telephonic communication	**1**		120 (140) km/h	**5**
	Train announcing points	**2**		160 km/h	**6**
	Semi-automatic block system	**5**			
	Automatic block system	**6**			

Source: Author

The choice of indicators to proceed to the merger of the indicators chosen because of their high countability. The differences of their influence and their subsequent evaluation have the same weight. As an example, we are presenting parameter of track class and their maximal loading where the track class is assigned a score of categories by alphabetic indexing without numerical index.
The model works with 11 groups of parameters, with total 42 indicators. The final evaluation of the track is the sum of the individual evaluation parameters that characterize the railway. Given the number of parameters of tracks allows at most score 66 points and no less than 11 points. In case if any parameter of the track is not in the matrix, it shall be assigned the value by weight closest possible parameters.
As an example parameter maximum line speed in the matrix evaluation, the maximum value of this ratio 160 km / h. If the proposed comprehensive review of lines applied to the track with the track speed higher than 160 km / h, shall be assigned to this indicator weight "6".

5.2. Determination of the conditions for „Ideal Track“

The ideal track is a track where individual factors are assigned the highest rating. This assessment will be a maximum assessment rate in all parameters.
For the evaluation of lines is necessary to establish conditions that would allow the creation of a comprehensive assessment model, relative to the track capacity, technical equipment etc.

6. Solutions

The solution to this design is the use and application of several optimization methods and algorithms. The final evaluation of the track is the sum of individual evaluation parameters that characterize a particular railway line.
Selection can be performed for any lines on the transport network, where is the possibility of building the new lines, ("building from scratch") or to determine directly choice the existing tracks.
The objective of the methods of multi-criteria evaluation is the transformation and synthesis values of different variables to a single summary indicator (the resulting characteristics). This indicator shows the comprehensive level of individual objects in the surveyed lines. It is a summary indicator representation of the overall level (importance) of the line.

$$Kj = \frac{\sum_{i=1}^{n} a_{ji}}{\sum_{i=1}^{n} a_{mi}}.100 \quad ; j \in 1,\ldots,m-1 \tag{6}$$

where:
Kj - coefficient of the j-th line;

$\sum_{i=1}^{n} a_{ji}$ - sum of the evaluation j-th line;

$\sum_{i=1}^{n} a_{mi}$ -sum of the evaluation the “ideal” line.

"Ideal line" is marked the line that all evaluation factors meets in full. Thus, the value x_{m1}, ... , x_{mn} are the maximum. Summary of indicators reflects the importance of the point. The basis of multi-criteria evaluation is processing the initial matrix of objects and their characteristics. The objects represent all railway lines on the network, which in each case meet the criteria for inclusion in a specific choice.

Table 6
Initial matrix for evaluation

Track / Indicator	1	2	...	j	...	m-1	m (the ideal line)
a_1	x_{11}	x_{12}				x_{1n}	x_{m1}
a_2	x_{21}	x_{22}				x_{2n}	x_{m2}
...	...						...
a_i				x_{ij}			
...	...						...
a_n	$x_{m-1,1}$	$x_{m-1,2}$				$x_{m-1,n}$	$x_{m,n}$
$\sum$	$\sum_{i=1}^{n} a_{1i}$	$\sum_{i=1}^{n} a_{2i}$		$\sum_{i=1}^{n} a_{ji}$		$\sum_{i=1}^{n} a_{m-1,i}$	$\sum_{i=1}^{n} a_{mi}$

Source: Author

Legend of the matrix:
$a_{1,\dots,n}$ – evaluation indicators;
x_{ij} – value of i-th indicator in the j-th railway line;
n – number of indicators;
m_{-1} – number of railway lines included to the initial matrix;
m – the ideal line.

7. Conclusion

The result of evaluation of the tracks can be classified into 4 groups, these groups are created by experts. Tracks of the highest final assessment can be classified in the first group of "I". Track with the lowest final assessment can be classified in the last group "IV". The boundaries between groups may be provided directly for the entire infrastructure or the inclusion of the tracks between the two groups will be assessed individually according to the overall complexity the track.
The guaranteed support railway by funding European Union or national governments is necessary that railway undertakings provide competitive transport services like other kinds of transport.
This model for evaluation railway lines represents one of the possible ways to meet the development strategy of the European Community's railways. By applying this model in practice can the infrastructure manager guarantee a higher quality of service and then expect an increase in performance. The model is also applicable for other network transport systems.

Acknowledgements

This paper was created within the framework of the following projects:
Project VEGA 1/0095/16 “Assessment of the quality of connections on the transport network as a tool to enhance the competitiveness of public passenger transport system”.
Project VEGA 1/0701/14 “The impact of the railway freight transport market liberalization on the social transport costs.”

References

Camaj, J. 2008. Optimization of train formation on transport network. *Dissertation theses*. 2008: 107.

Camaj, J.; Gasparik, J. 2008. Railway station evaluation for systematic train forming on the railway network. In: *Scientific Papers of the University of Pardubice, Series B – The Jan Perner Transport Faculty*, 14: 257-263**.**

Dolinayová, A.; Kanis, J.; Loch, M. 2016. Social and economic efficiency of operation dependent and independent traction in rail freight. In: *Procedia Engineering*, 134: 187-195.

Dolinayová, A.; Ľoch, M.; Kanis, J.2015. Modelling the influence of wagon technical parameters on variable costs in rail freight transport. *In: Research in transportation economics*, 54: 33-40.

Fotr, J.; Hořický, K. 1988. *Rozhodování. Řešení rozhodovacích problémů řízení*. Praha : Institut řízení. 238 p.

Gašparík, J.; Zitrický, V.; Ľupták, V. 2015. Vplyv modernizácie železničných koridorov ŽSR na ich kapacitu. IN *Proceeding of Horizons of railway transport*, 2015: 86-93.

Kendra, M.; Mašek, J.; Babin, M. 2014. Impact of railway infrastructure parameters on safety of goods transportation by railways. *In: Machines, technologies, materials: international virtual journal*, 8(3): 44-47.

Kendra, M.; Babin, M.; Šulko, P. 2013. Interaction between railway infrastructure parameters and quality of transportation services. *In: Proceeding of BulTrans- anniversary scientific conference on aeronautics, automotive and railway engineering and technologies*, 2013: 95-97.

Kendra, M. et al. 2016. Impact of the operation and infrastructure parameters to the railway track capacity. In: *International journal of civil, environmental, structural, construction and architectural engineering*, 10(1): 42-48.

Křupka, J.; Kašparová, M.; Machová, R. 2012. *Rozhodovací procesy*. Ustav systémového inženýrství a informatiky. Fakulta ekonomicko-správní, Univerzita Pardubice. 70 p.

Ližbetin, J.; Ponický, J.; Zitrický, V. 2016. The throughput capacity of rail freight corridors on the particular railways network**.** In: *Naše more znanstveno-stručni časopis za more i pomorstvo*, 63(3): 161-169.

Masek, J. et. al. 2015. Proposal and application of methodology of revitalisation of regional railway track in Slovakia and Serbia: Part 1: Theoretical approach and proposal of methodology for revitalisation of regional railways. In: *Transport Problems: international scientific journal*, 10(4): 85-95.

Skrucany, T. et al. 2015. Software simulation of an energy consumption and GHG production in transport. In: *Tools of transport telematics : 15th international conference on Transport systems telematics*, 151-160.

Zitrický, V.; Gašparík, J. 2015. The use of the allocated of train paths in terms of ZSR. In: Proceeding of *LOGI 2015: 16th international scientific conference*, 55-62.

ŽSR. 2015 Network Statement 2015/2016. Available from Internet: <http://www.zsr.sk/anglicky/railways-infrastructure/marketing/network-statement/network-statement-2016.html?page_id=3655>.

IDENTIFICATION OF THE CYCLICAL COMPONENT IN MODELING ROAD ACCIDENTS

Dariusz Grzesica[1]
[1] *Institute of Construction and Transportation Engineering & Management, Transport Section, Cracow University of Technology, Cracow, Poland*

Abstract: The World Health Organization estimates that road traffic accidents are on the 8th place in the ranking of causes of death of the world's population. In addition, from the point of view of the economy, they generate very large external transportation costs. The term, therefore, changes the number of occurrence of road traffic accidents in specific time periods, will allow a better understanding of this phenomenon and counteract their negative effects. The number of road accidents depends on many parameters like infrastructure, or drivers behavior. Many of these factors is cyclical in nature, i.e. is repeated in certain intervals. To identify the cyclical component spectral analysis will be used on data obtained from three time intervals: monthly, weekly and daily. The time series from the point of view of stationarity will be reviewed. On this basis the model will be built as a sum of trigonometric functions that describe the changes of the time series, the result of the influence of the cyclical factor. Individual harmonics of the high level of amplitude will substantially explain the variability of this series.

Keywords: identification of cyclicity, spectral analysis, stationarity of the time series, periodogram.

1. Introduction and background

Modern societies cannot function without transport which, in turn, causes obvious problems such as traffic accidents, pollution, and noise (Stoupel et al., 2009). Road accident data analysis plays an important role in identifying key factors associated with road accidents. Once the road accident factors are identified, the proper actions can be taken to overcome the accident rate. These factors help in taking preventive measures to overcome the road accidents. In work (Ceausu and Desprès, 2006) they presents a system, which explains the method of accidents analysis. The analysis is carried out in order to recognize within accident reports general mechanisms of road accidents that represent prototypes of road accidents. This can be achieved through proper use of the data mining. Data mining techniques do not require certain assumptions between dependent and independent variables which are required in traditional statistical techniques (Chen and Jovanis, 2002; Więcek et al., 2014).
One of the factors that can explain the variability in the number of accidents occurring in time is cyclicity. The cyclical component can be determined using spectral analysis. Spectral analysis is not widely used in the field of transport and logistics, best in events lasting more than one year. However, there are some attempts to use this method in traffic. Due to the fact that phenomena in transport are relatively fast and with high frequency, it is possible to allocate the cyclical changes in it occurring from time to time. Parry with her colleagues worked on traffic periodicity in a short term (Perry et al., 2013). In (Levine et al., 1995), they identified weekly pattern in motor vehicle accidents. In turn, (Zhang et al., 2014) built a hybrid short-term traffic flow forecasting method based on spectral analysis. There is a lack of works that use spectral analysis tool to determine the cyclical component in the field of transport.

2. Data preparation

The main purpose of spectral analysis is to draw attention to the cyclical processes. It involves the wave structure of the waveform variables stochastic processes which allows to analyze the spectrum in frequency domain. This is possible through the use of trigonometric functions sine and cosine, often called harmonics. The magnitude of harmonics for *n* observations is *n*/2. First harmonic has a period equal to *n*, the second *n*/2, one in *n*/3, etc.
Spectral analysis allows to reveal cyclic fluctuations in the data contained in the time series. Thus, there is the ability to determine the cyclical changes that occur in a certain period of time. A necessary condition for using spectral analysis is to have a relatively large amounts of data. The more data, the more likely it is to find a cyclicity in the analyzed time series.
At the initial stage of work it is necessary to check whether a time series is stationary. In order to study the stationarity of the data the advanced Dickey Fuller test was used. It is the other name for unit root test account for possible autocorrelation of the random component (ADF) (Dickey and Fuller, 1979). If the series is nonstationary, it comes down to stationarity by calculating successive differences: $\Delta y_t = y_t - y_{t-1}$. If the time series is still nonstationary, this process is repeated until it reaches stationarity.
Calculations were made using data for the period from 1 January 2012 to 31 December 2015. For the detection of cyclicity in different periods of time, the data recorded for each day was divided into three groups: the monthly period for four years, weekly, in the period from 1 December 2014 to 31 December 2015 and daily from 14 November to 31 December 2015. Each of the studied periods has 44 recorded observation, which will allow to optimize the calculation process. The calculations for weeks and days in the whole research period is not required, as old data affect the explanation of the studied time series in the slightest degree.

[1] Corresponding author: dgrzesica@pk.edu.pl

3. Methodology

3.1. Stationarity of the time series

For data from three time periods was conducted a comprehensive Augmented Dickey Fuller stationarity test to determine the degree of integration of the series. The conclusion was made for a significance level of p=0.05. In this case, the p-value is less than 0.05, evidence of stationarity of time series (Fig. 1).

Fig. 1.
Stationary and nonstationary data in three studied time periods
Source: own elaboration

Monthly and daily time series is close to stationarity, so it’s no need to be differentiate, and the weekly time series is nonstationary. After differentiation it has been brought to stationarity.

3.2. Periodogram in spectral analysis

To detect the occurrence of cyclical component in the studied time series describing the number of road accidents it is possible to use a periodogram. It is used as an estimator with spectral analysis. Effective mainly for the function is clearly periodic. In the periodogram the value of density spectrum increases as the sum of sine and cosine waves. The frequency of these waves is a multiple of the inverse of the length of the analyzed series. Periodogram shows the proportion of the total variance of the sum of harmonic oscillations at the frequencies contained in the interval (ω, $\omega+\Delta\omega$). Periodograms for the individual time intervals is represented in Fig. 2.

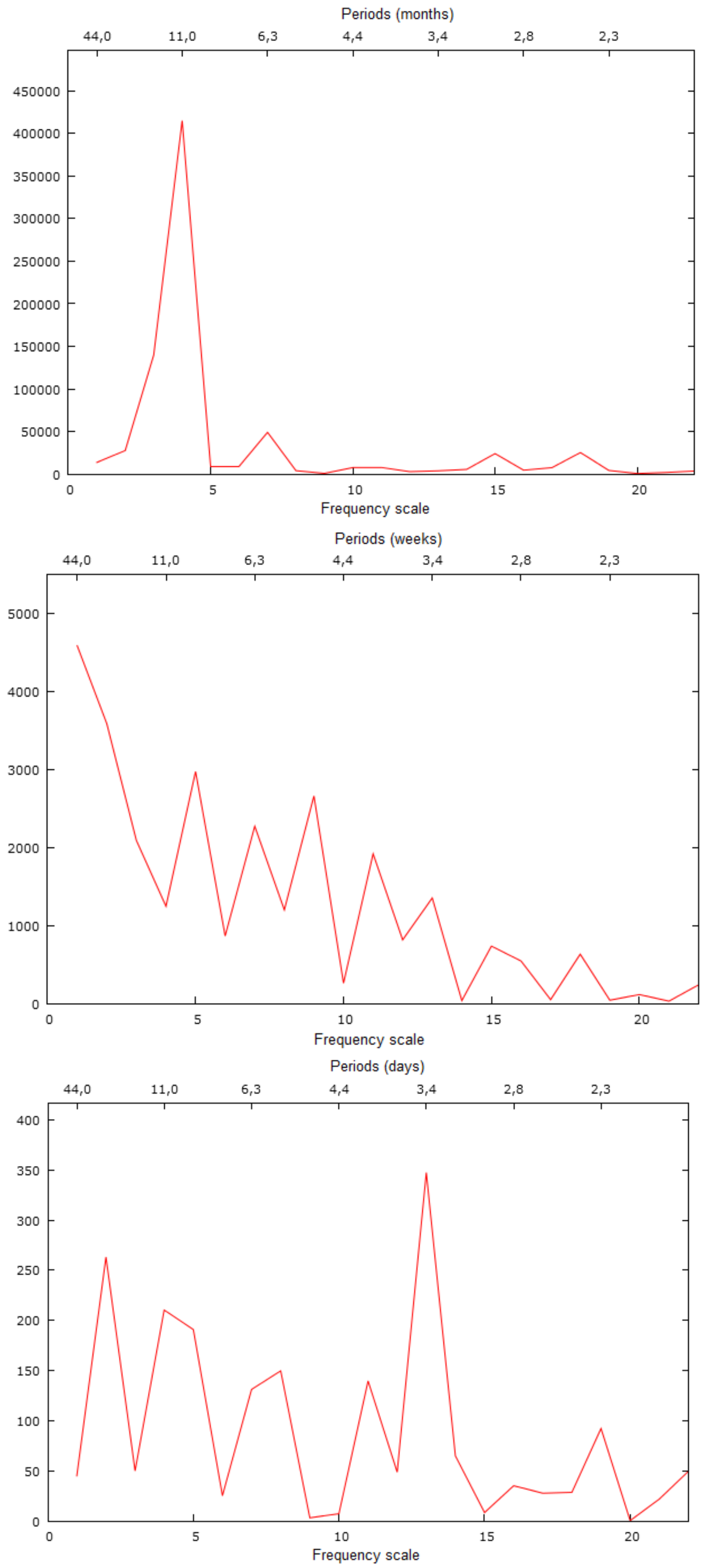


Fig. 2.
Periodograms for three studied periods
Source: own elaboration

As seen on the periodograms in each time period there are large fluctuations, which means that the time series is characterized by frequency variation. During monthly there is one big loop, while in others there are much more of them. In this position we can conclude that the series contain cycles, which appear from time to time.

3.3. Spectral analysis model to identify the cyclical nature of time series

Spectral analysis model is constructed as the sum of harmonics, i.e. the functions sine and the cosine of the specified period. The quantity of all harmonics is *n*/2. After elimination of trend by the differentiation method is required to estimate the model parameters α_0, α_i, and β_i:

$$y_t = \alpha_0 + \sum_{i=1}^{n/2} \left(\alpha_i \sin\left(\frac{2\pi}{n} \cdot i \cdot t\right) + \beta_i \cos\left(\frac{2\pi}{n} \cdot i \cdot t\right) \right) \tag{1}$$

Parameters are estimated by the least squares method using the formulas:

$$a_0 = \frac{1}{n} \sum_{t=1}^{n} y_t \tag{2}$$

$$a_i = \frac{2}{n} \sum_{t=1}^{n} y_t \cdot \sin\left(\frac{2\pi}{n} \cdot i \cdot t\right), \text{for } i = 1, \ldots, \frac{n}{2} - 1, \tag{3}$$

$$b_i = \frac{2}{n} \sum_{t=1}^{n} y_t \cdot \cos\left(\frac{2\pi}{n} \cdot i \cdot t\right), \text{for } i = 1, \ldots, \frac{n}{2} - 1, \tag{4}$$

The longer time series, the greater number of harmonics which can be define. Most often there is no need of considering all possible harmonics. Uses those which are involved in the explanation of the variance of the applicants variable. This contribution can be determined from the formula:

$$\omega_i = \frac{c_i^2}{2s^2} \tag{5}$$

while for the last one:

$$\omega_i = \frac{c_i^2}{s^2} \tag{6}$$

where:

$$c_i^2 = a_i^2 + b_i^2, \tag{7}$$

s^2 – is the estimate of variance considered variable.

4. Results

4.1. Identification of cyclicity in time series

For the adopted assumptions, harmonics were extracted, which most explain the cyclical fluctuations in the studied time series. The number of harmonics and percentage in order from the biggest to the smallest cyclic changes are presented in Table 1.

Table 1
Review of a harmonics in the studied time periods

Time period	No. of selected harmonics [-]	Percentage in explaining cyclicity [%]	Summary percentage [%]	Time period	No. of selected harmonics [-]	Percentage in explaining cyclicity [%]	Summary percentage [%]
Monthly	4	76.55	76.55	**Daily**	13	18.1	74.77
Weekly	1	16.31	71.42		2	13.7	
	2	12.75			4	11	
	5	10.57			5	10	
	9	9.46			8	7.8	
	7	8.08			11	7.3	
	3	7.43			7	6.8	
	11	6.82					

Source: own elaboration

On the basis of the summary percentage of variability explanation of frequency domain shows that the clearest cyclicity dominates on a monthly basis, up to 76.55%. The rest harmonics participate in the explanations below the 3.6%, so they were not included. Another is the variability of the daily cost is equal to total 74.77% (the highest value harmonic is 18.1%) and weekly equal to 71.42% (the highest value harmonic is 16.31%).

From Table 1 it is seen that in the monthly periods, the cyclical occurrence of road accidents has a period of twelve months. This means that the number of accidents each year has a periodic pattern of changes.

4.2. Models based on the cyclical changes in road accidents

For making models the harmonics from table 1 were used. They have the greatest impact on the explanation of the time series. For the monthly period of time the data remain stationary. The model can be created by using the formula:

$$y = 2568{,}16 - 495{,}636 * sin(2 * \pi/44 * 4 * t) - 246{,}223 * cos(2 * \pi/44 * 4 * t) \quad (8)$$

The model is quite simple as it contains only one harmonic, which explains the changes recurring in more than 76 %. On the basis of the formula (8) you can create a course explaining changes in the number of accidents on a monthly cyclicity (Fig. 3).

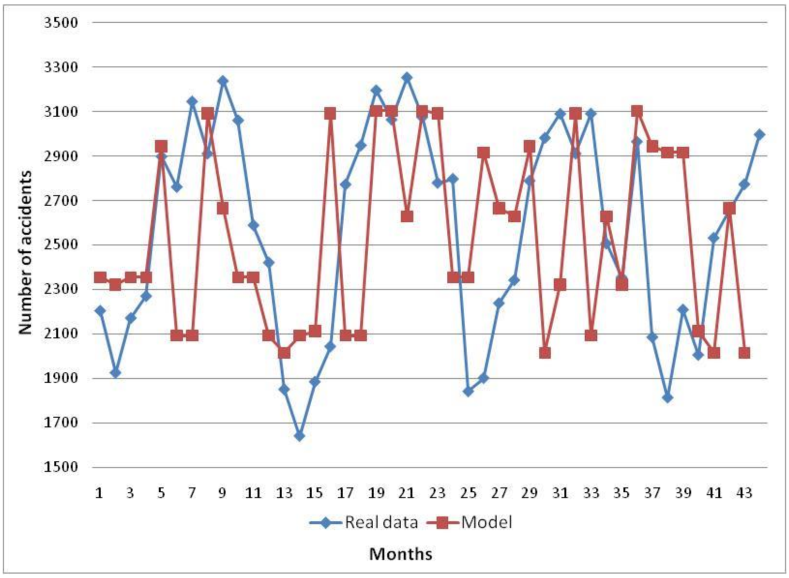


Fig. 3.
Model based on monthly cyclicity
Source: own elaboration

The correctness of the developed model is confirmed by measuring compliance, called the coefficient of determination. For the presented model it is 0.72. This indicates the strong adjustment of the linear regression model for real data.
The model takes into account the trend for weekly cyclicity will be created on the basis of the formula:

$$y_t = f(x) + \sum_{i=1}^{n/2} \left(\alpha_i \sin\left(\frac{2\pi}{n} \cdot i \cdot t\right) + \beta_i \cos\left(\frac{2\pi}{n} \cdot i \cdot t\right) \right) \quad (9)$$

where:
f(x) –trend function.

The obtained model can be formulated as follow:

$$y = 2{,}5484 * t + 517{,}21 - 36{,}33 * sin(2 * \pi/44 * t) + 36{,}02 * cos(2 * \pi/44 * t) + 27{,}12 * sin(2 * \pi/44 * 2 * t) + 36{,}22 * cos(2 * \pi/44 * 2 * t) + 32{,}96 * sin(2 * \pi/44 * 3 * t) + 10{,}33 * cos(2 * \pi/44 * 3 * t) + 37{,}34 * sin(2 * \pi/44 * 5 * t) - 17{,}38 * cos(2 * \pi/44 * 5 * t) + 0{,}6 * sin(2 * \pi/44 * 7 * t) - 36 * cos(2 * \pi/44 * 7 * t) - 7{,}2 * sin(2 * \pi/44 * 9 * t) - 38{,}3 * cos(2 * \pi/44 * 9 * t) - 33{,}07 * sin(2 * \pi/44 * 11 * t) + 1{,}21 * cos(2 * \pi/44 * 11 * t) \quad (10)$$

The model together with the actual data is shown in Fig. 4

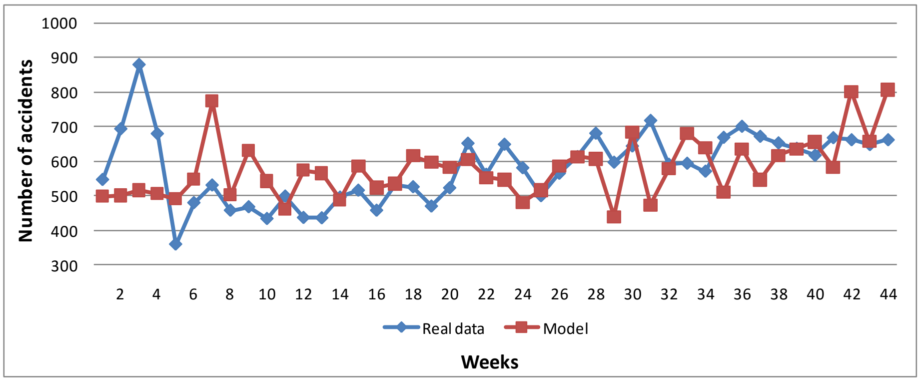


Fig. 4.
Model based on weekly cyclicity
Source: own elaboration

Measuring compliance for this model is 0.71.
For daily cyclicity model can be formulated as follow:

$$y = 91{,}522 - 12{,}2525 * sin(2 * \pi/44t) - 0{,}3824 * cos(2 * \pi/44 * t) - 10{,}033 * sin(2 * \pi/44 * 4 * t) + 26{,}6 * cos(2 * \pi/44 * 4 * t) + 0{,}0435 * sin(2 * \pi/44 * 5 * t) + 10{,}44 * cos(2 * \pi/44 * 5 * t) - 6{,}01 * sin(2 * \pi/44 * 7 * t) + 6{,}227 * cos(2 * \pi/44 * 7 * t) - 9{,}118 * sin(2 * \pi/44 * 8 * t) + 1{,}532 * cos(2 * \pi/44 * 8 * t) - 2{,}591 * sin(2 * \pi/44 * 11 * t) + 8{,}5455 * cos(2 * \pi/44 * 11 * t) - 8{,}025 * sin(2 * \pi/44 * 13 * t) + 11{,}577 * cos(2 * \pi/44 * 13 * t) \quad (11)$$

The model together with the real data shown in Fig. 5.

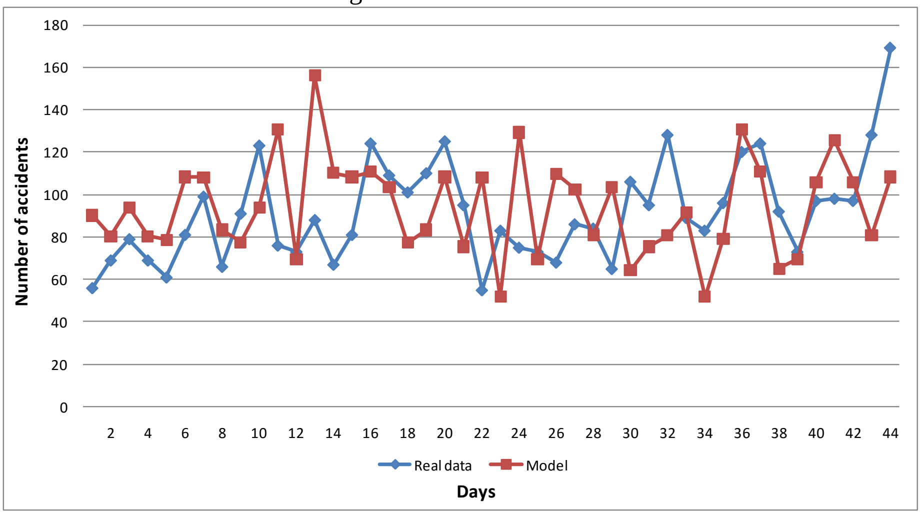


Fig. 5.
Model based on daily cyclicity
Source: own elaboration

Measuring compliance for this model is 0,89.
From the three investigated types of cyclicity, the model is best suited for daily data. This implies that diurnal cyclicity is the most powerful. The rest, monthly and weekly, have similar measuring compliance at the level of 0.71.

5. Conclusions

Method of spectral analysis was used to study cyclicity of the occurrence of road accidents. Using this technique, you can easily determine the amplitude of the time series, i.e. the harmonics. Investigated were three periods of time: monthly, weekly and daily. From the conducted research it follows that one harmonic in 76.55 % explains the cyclical changes in the series. In other cases, the level of explanation cyclicity is slightly less, but for its explanation it is necessary to use 7 and 6 harmonics. Based on them models were built to determine changes in the number of road accidents. Comparing the cumulative percentage of explanation of the existence of cyclicity with the measure of association shows that it is biggest for daily periods.
Spectral analysis is used for long periods, longer than a year, however, finds application in the study of daily variables. It can help to identify the cyclical changes in the magnitude of road accidents and, consequently, respond accordingly in order to reduce the number of their occurrence.

References

Ceausu, V.; Desprès, S. 2006. Towards a case-based reasoning approach to analyze road accidents. In Professional Practice in *Artificial Intelligence Volume 218 of the series IFIP International Federation for Information Processing*. 257-264 p.
Chen, W.; Jovanis, P. 2002. Method of identifying factors contributing to driver-injury severity in traffic crashes, *Journal of the Transportation Research Board,* 1717: 1-9.
Dickey, D.A.; Fuller, W.A. 1979. Distribution of the Estimators for Autoregressive Time Series with a Unit Root, *Journal of the American Statistical Association*. No. 74.
Levine, N.; Kim, K.E.; Nitz, L.H. 1995. Daily fluctuations in Honolulu motor vehicle accidents, *Accident Analysis & Prevention*, 27(6): 785-796.
Parry, K.; Watling, D.P.; Hazelton, M.L. 2013. A new class of doubly stochastic day-to-day dynamic traffic assignment models, In *EURO Journal on Transportation and Logistics*, 5-23.
Stoupel, E.; Babayev, E.S.; Shustarev, P.N.; Abramson, E.; Israelevich, P.; Sulkes, J. 2009. Traffic accidents and environmental physical activity, *International Journal of Biometeorology,* 53(6): 524 p.
Więcek, P.; Grzesica, D.; Kubek, D. 2014. The advanced prediction method of inventory costs in coal mine industry. In *Proceedings of the Second International Conference on Traffic and Transport Engineering ICTTE*, November 27-28, Belgrade 2014. 517-524.
Zhang, Y.; Zhang, Y.; Haghani, A. 2014. A hybrid short-term traffic flow forecasting method based on spectral analysis and statistical volatility model, *Transportation Research Part C-Emerging Technologies. Special Issue*, 43: 65-78.

MODELLING OF INTRA PLANT TRANSPORTATION SYSTEM USING AGV

Hana Neradilova[1], Gabriel Fedorko[2], Viktoria Borsosova[3]
[1] College of Logistics Prerov, Palackeho 25, 750 02 Prerov, Czech Republic
[2,3] Technical University of Kosice, Letna 9, 040 01 Kosice, Slovakia

Abstract: AGV are currently being used in important industrial companies to ensure supplying and to ensure the functioning of interoperable transport and shipping finished products. Increasingly they replace conventional transportation technologies. In the contribution it will be described a creation of a simulation model of supplying assembly lines using AGV in Tecnomatix Plant Simulation software. For very accurate approximation to reality the method of complementary programming in language SimTalk was used within the model creation. The presented model allows to analyse the utilization of individual workplaces and to verify the process of material supply. The simulation model was created for the purpose of analyzing logistic processes in a company.

Keywords: AGV, simulation, analysis, transport, supply.

1. Introduction

Automated logistics systems represent a comprehensive solution of automation within the enterprise logistics in different industrial sectors. The objective of deploying automated logistics systems is to increase the efficiency of individual logistic operations (Tomkova et al., 2015). Onset of automation is visible already for a longer time especially in the automotive industry for assembly lines, but also in warehouses and distribution centres. Currently harder and harder market environment and constantly resurgent competition are a challenge for designing and modelling of reliable, safe and flexible manufacturing processes, operations and workplaces. Industrial automation and robotization are no longer only fancy trend but a necessity with a view to increasing the efficiency of establishments, departments, technologies and processes. Designing and projecting of AGV systems is not easy task. Mastering this task requires a wide range of knowledge. Fazlollahtabar (Fazlollahtabar, 2016) dealt with the draft of parallel automated line for the production of different products. He considered AGV system with auto-guided for their supplying. When planning a travel route the main problem was the time schedule of each operation. AGV systems are used for carrying loads of different sizes. Use AGV system within the container terminal is described in the paper Research on scheduling problem of multi-load AGV at automated container terminal (Huo et al, 2016). In the paper he describes the use of genetic algorithm method. The issue of time planning of freight distribution is another from problem areas, which is currently the object of research in connection with the AGV. Wang and Zhou devoted themselves to these issues. They dealt with issues of AGV operation planning in flexible manufacturing systems (Wang and Zhou, 2016). Further work dedicated to AGV operation planning is Multi AGV scheduling problem in automated container terminal by authors and Jin and Zhang (Jin and Zhang, 2016). At present, each AGV systems have various methods of guidance on transport routes. One possibility is e.g. usage of a camera for motion control as it is presented in the work of Ishizuka and Hidaka. AGV is currently one of the leading areas of research in the field of logistics. Kumar further discusses this fact at all. As part of their contribution there is more detailed description of computer simulation method as the main comparative tool for research on the properties of different variants of AGV systems (Kumar et al, 2015).

2. Characteristics of automated logistics systems

Automated logistics systems resulting from long-term pressure to improve and accelerate the services provided in the field of logistics. The manufacturing process of the products and their distribution to the ultimate consumer, it is constantly improving, accelerating and automation is one of the tools to achieve the specific requirements. Automation process touches directly or marginally e.g. material handling, supplying, and consequently it affects the quality, continuity and efficiency of the entire logistics process. In general, automated transport logistics systems can be divided into two basic groups:

- Conveyor systems,
- Automated control systems of transport vehicles and material handling vehicles.

2.1. Conveyor systems

Conveyor systems are widely used within logistics (Ficzere et al., 2014). They can be used e.g. for handling and transport of pallets between automated warehouse stacker and off-load places. The system may comprise conveyors, either the roller or chain and the other additional equipment such as a hoist, rotary drives, transfer stations, automatic tractors and warehouse pallet stackers (Szendrő and Török, 2014). All operations are automated and software controlled to minimize time and maximize operational efficiency of the storage process (http://www.mecalux.sk/automaticky-sklad-palety/zakladac).

[1] Corresponding author: hana.neradilova@vslg.cz

Conveyor systems for boxes (Fig. 1) provide automated transport within individual work places thereby increasing the efficiency of handling crates or boxes during storing and delivering from warehouse.

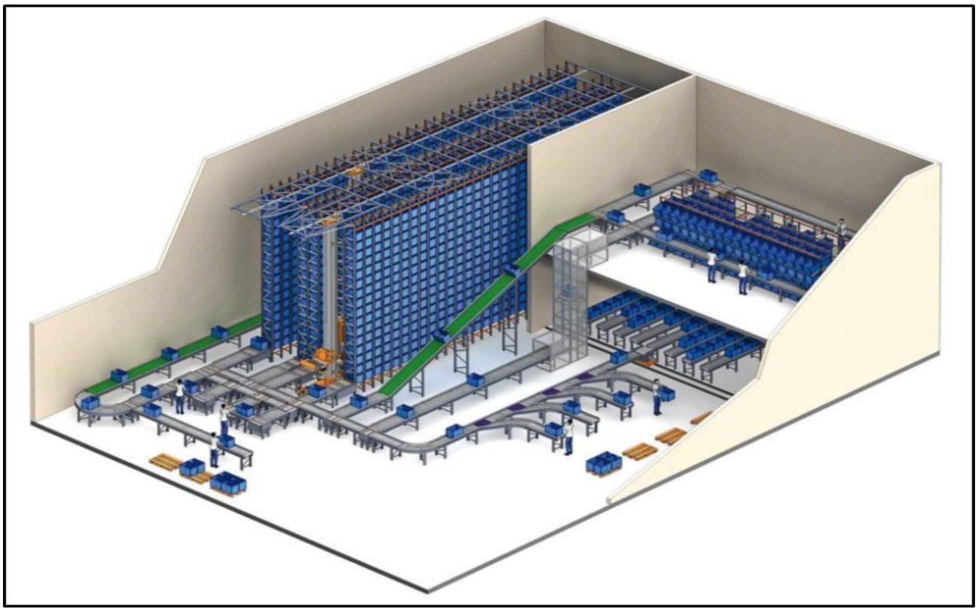


Fig. 1.
Conveyor system for boxes
Source:https://encryptedtbn2.gstatic.com/images?q=tbn:ANd9GcRI7qlwXTn_6tgdPcVsEKhwW8Lj-WKBgLDdlCer1Br541UMhdTvVA

2.2. Automated control systems of transport vehicles and material handling vehicles

Automated guided systems for vehicles can be classified as a developed and dynamic sphere within the handling of goods. Years of development have enabled the progress in guiding vehicles by laser or other principles. Technological development has increased flexibility, application diversity and the ability of automated guided systems of vehicles.
System AGV **-** automated guided vehicle (AGV) **-** the unmanned autonomous device, which moves for example on the predetermined path. The movement is controlled by a combination of software and guidance systems, and it follows that the devices do not require human intervention. The most common use of AGV system is in companies where handling the large amount of materials in production halls or warehouses. Cargo is usually transported in trailers that are in the coupling (Fig. 2), (Ullrich, 2015).

Fig. 2.
A sample of AGV system with coupled trailers
Source: http://ceittechinnovation.eu/index.php/sk/agv-system

Currently AGV systems are popular and recorded a significant rise, as not only simplify and facilitate material handling, but its independence improve efficiency and reduce the cost of human operators in logistics. AGV are vehicles designed for handling materials and products inside a company, they save time, energy and space within the enterprise logistics. Vehicles can communicate with other robots or with other automation systems to ensure smooth handling of material (Štusek, 2007).

2.2.1. Basic parts of AGV system

Basic parts of AGV system are shown in the following diagram (Fig. 3).

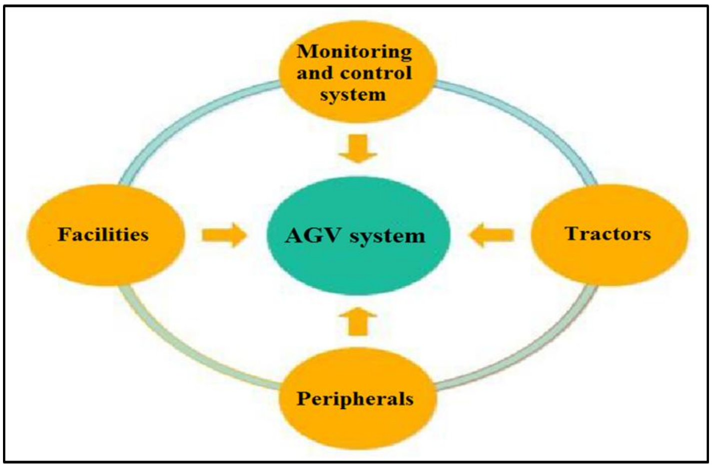


Fig. 3.
Basic parts of AGV system
Source: Authors

AGV tractors
Automatic tractors are ranked among the standard equipment for AGV systems, which are used to transport material. The devices are usable in every sector of industry and the only condition for their use is an existence of industrial poured floors on which surface the AGV move. Tractor allows distribution of goods in the logistic flow through various peripherals on basis of connection method (http://ceittechinnovation.eu/index.php/sk/agv-system).

AGV peripherals
AGV peripherals represent drawn transport equipment behind a tow bar of automatic tractors that enhance flexible logistics system complexity. Among AGV peripherals is possible to include conventional models of wagons, assemblers, conveyors and their modified versions. Selection of peripherals is influenced by the type of transported material or transported unit (http://ceittechinnovation.eu/index.php/sk/agv-system).

Facilities - Navigation systems
For solving navigation systems can be used the following options (Ullrich, 2015):

- Inertial or gyroscopic navigation - allows a computer to determine the direction and give orders to vehicles,
- Guidance tapes - for determining guide path are used tapes, which can be of two types - coloured or magnetic,
- Guideline in the floor - the wires are located several centimetres below the floor surface and conduct a full length of the route along which a tractor is moving,
- Laser navigation - a form of wireless navigation using reflective materials placed on poles, shelves, walls and equipment,
- GPS navigation – the global positioning system is ideal for outdoor use vehicles. One condition for the correct GPS is line of sight between the satellite antenna and antenna receiver on the vehicle to capture the radio signal.

Monitoring and control system
Monitoring and control system plays a key role in integrating the AGV system with its surroundings. This involves advanced hardware-software product that is used for tracking, managing, monitoring automatically guided vehicles and their peripherals and the continuous collection and evaluation of information about the system (Molnar, 2012). Mutual communication between logistics equipment and the system is provided by radio or Wi-Fi signal. Obtained information about the system are processed and transferred into a user-friendly form, usually into a graphic form. The user has the ability to change system elements through this system (http://ceittechinnovation.eu/index.php/sk/agv-system)

2.2.2. AGV categories

AGV systems categorization and division is not easy to implement, because their development constantly follows current trends in logistics. Nevertheless, one option AGV categorization is by Ullrich (Ullrich, 2015).

- Forklift AGVs – their range of use is very wide. Logistical tasks performed by this type of AGV can be simple or very complex. They are designed for handling with standard pallets, special pallets or compatible containers,

- Piggyback AGVs – vehicles allow manipulation of conventional transport units such as pallets, containers or cages, but they are not able to pick up the units directly from the floor. Transport units are required to be lifted and loaded by other device typically to the height of 60 cm,
- Towing vehicle – it allows perform simple movements there and back. When it comes to destination, it will stop and wait for employees to exchange trailers. The vehicle itself serves only to towing,
- Underride AGVs – are specialized in transporting roller carts and roller containers by lifting them up and moving. This type is widely used in hospitals,
- Assembly AGVs – are applied in serial assembly, supporting structure carries the assembly object and assembly process is done directly on the AGV system. Driving speed is extremely low,
- Heavy load AGVs – are used either in the production or processing of paper, steel and in automotive industry and they are used for the transport of steel coils, large paper roll, etc,
- Mini AGVs – small, smart and flexible vehicle that is capable of performing tasks quickly. Vehicles should be able to mutually cooperate and execute an intended task. They have greatest use in assembling shipments to customers, finding and collecting goods in storage areas,
- PeopleMover AGVs – are used to transport passengers, they are mostly used in outdoor areas, or in public areas,
- Diesel AGVs – this category includes vehicles used in outdoor areas to transport materials in larger masses. The outdoor use allows utilization of the drive,
- Special design AGVs – are vehicles designed for special projects and vehicles, which cannot be classified in the previous categories.

3. Creation of a simulation model of automated transportation system

As it was mentioned in the introduction, one of the effective methods for analysis and research of AGV systems is a computer simulation method (Strohmandl, 2014). Its use will be presented with a simple example. To create a simulation model of automated transportation system was chosen simulation program for creating models of production processes and management strategies Tecnomatix Plant Simulation.
Primary in creating a simulation model was the placement of individual workplaces and warehouse and determining the route on which logistic trains will run (Fig. 4, Fig. 5). The analyzed company is focused on production and assembly of small parts, which has its own warehouse of input material with regular orders from external suppliers. Production and assembly take place in the same hall in which five automated workplaces are stationed. Material flow within the manufacturing and assembly hall is provided by set of vehicles on circular route that connect all departments. Basic components are sequentially processed in various manufacturing or assembly processes such as shaping, stamping, trimming, varnish and so on. Conveyor belts are used in the three workplaces to ensure automated component handling for assembly machines. After a one-way circular route there are 11 stations, which provides the necessary loading or unloading of the various components transported in transportation units.

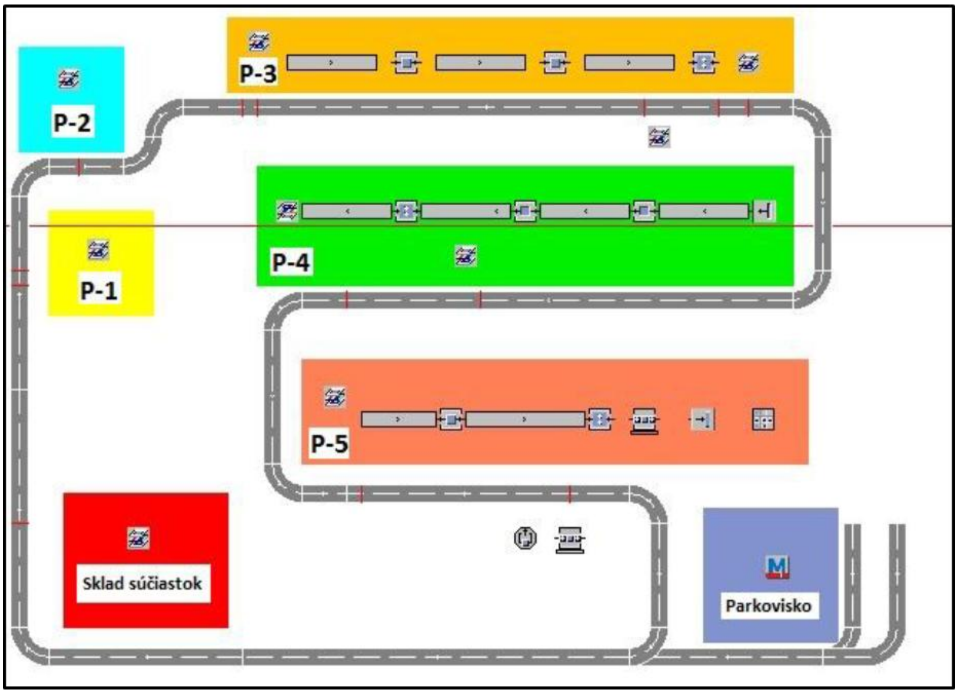


Fig. 4.
The placement of workplaces in the production hall
Source: Authors

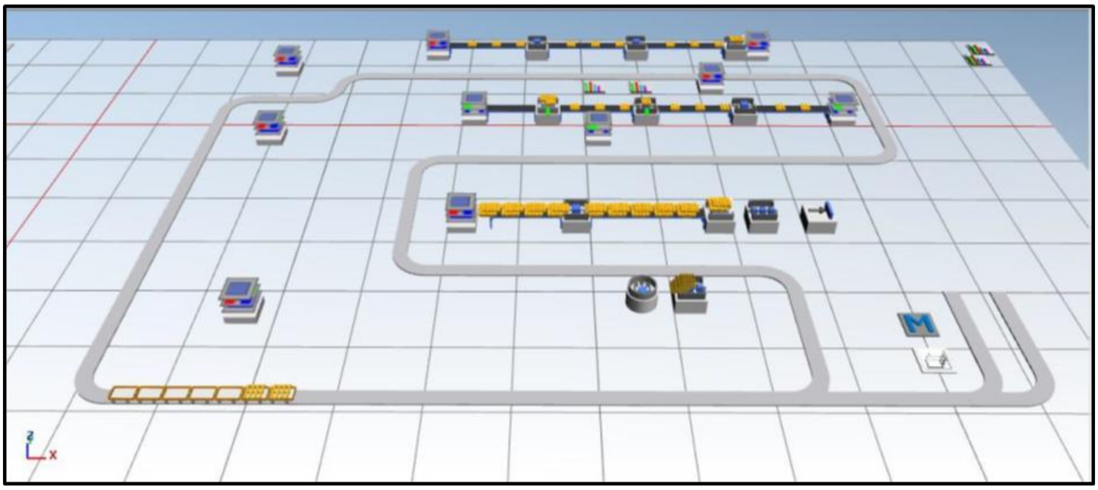


Fig. 5.
3D model of the production hall
Source: Authors

3.1. Creation of moveable units

The moveable units are active logistic elements, which are getting into motion within the simulation model. Therefore, an important step in creating the model is to define all moveable units including all trailers and tractor units, transportation units and transported material itself. Moveable units differ in the name as well as in their predefined attributes that are set individually by double-clicking on the item. In addition to size of units, also capacity of trailers and transportation units are set.

3.2. Creation of workplaces

Each workstation represents a new and hierarchically arranged unit within the simulation model. Warehouse of components is the first stop for set of vehicles. Based on the assumption that the firm receives necessary components to the store at regular intervals, warehouse of components by using blocks "Source" generates all the necessary materials, components for the production of finished product at regular intervals, this means that during the simulation is never any shortage of these components.
Block "Assembly" allows to load into the transport unit as many components as many is defined in it. Also the information is needed about which connector goes the main movable unit through and the material should be loaded on. "Transfer Station" is the key block for loading and unloading. It determines place from where to where the material is transported, what type of material, and which tractor will perform the activity. Empty transport units removed from some workplaces on trucks are unloaded in the warehouse where they exit the simulation model over the block "Drain" (Fig. 6).

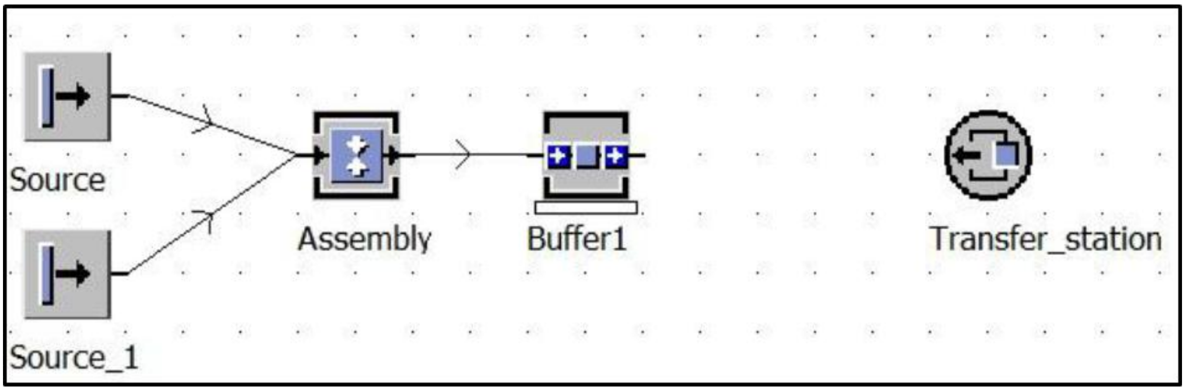


Fig. 6.
The basic model structure of component storage
Source: Authors

Warehouse of components generates 6 kinds of components representing 6 blocks "Source" for components and also 6 transport units so it means further 6 blocks "Source" for generating transport units. As it was mentioned, the production and assembly include 5 automated workstations (Table 1).

Workstation 1 follows immediately after the warehouse on the circular route and there are unloaded two different types of components in the transportation units. After unloading the components are discharged from transport units into the containers. At the workplace no.1 the components are assembled in two assembly machines. Semi-finished products made by connecting are gathered in the stock bin "Buffer", re-loaded into the transport units and waiting for loading due to relocation to the place of further processing it means to the Workstation 3. Empty transport units are transported back to the store.
Workstation 2 is identical to the Workstation 1 in the composition and operation of the processes. The difference is in using another kind of components from the warehouse and installation of components is carried out by only one assembly machine. The outputs from the Workstation 2 are semi-finished products intended for further processing at the Workstation 6 (the finishing workstation).
Workstation 3 - the first step is again unloading the material by using "Transfer Station". Along the Workstation are three stops, at the first stop one type of components is put out in transport units, the components after unloaded from crates moving on a conveyor belt. In the Workstation 3 there are three conveyor belts 7 metres long that connect the place of unloading material with two machines, in the simulation model these are blocks "SingleProc“ that carry out the necessary adjustment of input components. At the end of the last conveyor belt adjusted component joins the semi-finished product from Workstation 1, which is unloaded at the second stop. Transport units, in which the components were brought, are moved by transport truck to the endpoint of Workstation 3, where adjusted components waiting for loading and displacement at the Workstation 4.
Workstation 4 is identical to the Workstation 3 in the composition and operation of the processes, unlike workstation 3 it has four conveyor belts that connect all processes at workstation as well together with the loading. The workstation is supplied with input material from the warehouse and after adjustment is connected with an output semi-manufacture from Workstation 3. From the loading place the products are moved to Workstation 6.
Workstation 5 is the last workplace where the semi-manufactures sequentially formed on the previous workstations are joined and at the end a finished product is produced. After the last process which is the varnishing, the products are loaded into the transport units and exiting the simulation model.
The aim of creating workstations was to create the necessary links for the proper functioning of the manufacturing and assembly processes. Also the parameters were set for the simulation experiments, which remained constant during the simulation experiments.

Table 1
Summary of workstations

Workstation	Process	Duration (sec)	Machines (number)	Loading/Discharge (sec)
Workstation 1	assembly	30	2	5
Workstation 2	assembly	18	1	5
Workstation 3	trimming	15	1	5
	shaping	15	1	5
	assembly	10	1	5
Workstation 4	cut-out	15	1	5
	stamping	15	1	5
	assembly	10	1	5
Workstation 5	assembly	15	1	5
	varnish	10	1	5

Source: Authors

The aim of creating the simulation model was to define all necessary moveable units and set their attributes, to allocate workplaces in which were created the necessary relations for the proper functioning of the production process, to define circular route and to form set of trailers. The outcome is a functional simulation model that simulates a work shift for the time of 8 hours.

4. The use of a simulation model of automated transportation system

One of the main efforts of the company is to achieve maximal smoothness and synchronization of logistics and production processes. The automatic transport system is one way to do this. For monitoring and improvements of the simulation model was carried out several simulation experiments. After setting the amount of stocks and storage capacity has been launched and pursued a simulation model that after 8 hours of work produced 1,360 pieces of finished products. The monitored model showed no errors during the simulation time and after simulating 8-hour work shift was successfully completed. The effort in creating the model was to determine the optimal amount of inventory for all departments in order not to create unnecessary untapped stocks in the workplaces and at the same time ensure the continuity of production processes. The result of running the simulation model has been the finding that the amount of inventory that was defined when creating the simulation model is too large. The following figure (Fig. 7) shows the state at the Workstation 1 after 8-hour work shift.

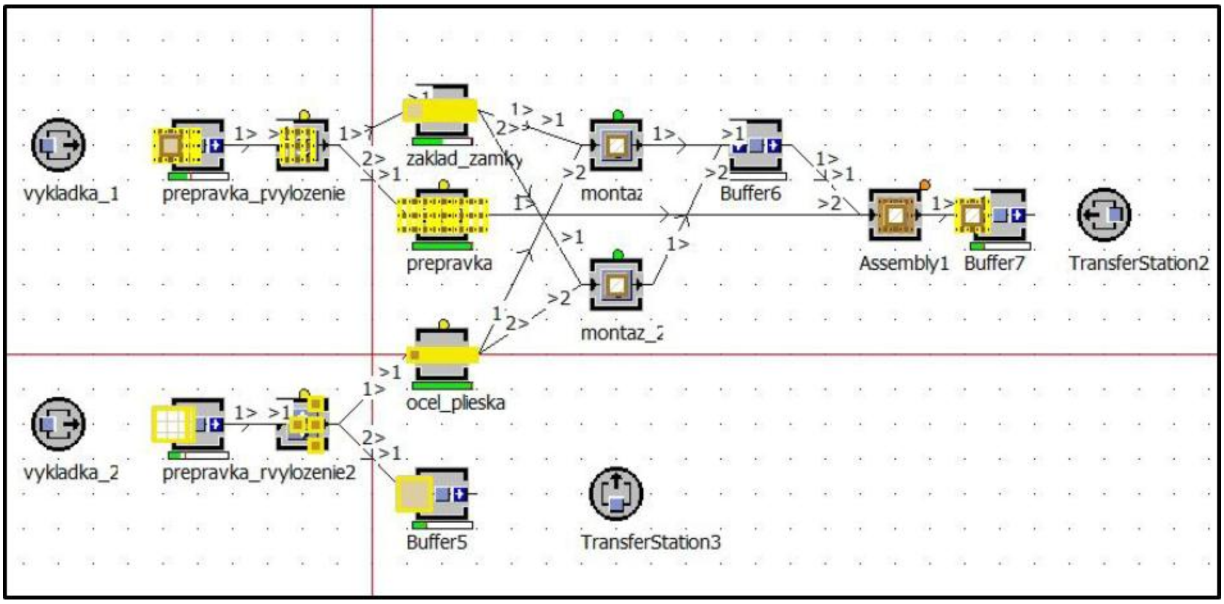


Fig. 7.
State at the Workstation 1 after 8-hour work shift
Source: Authors

The Workstation 1 is an important link throughout the manufacturing process, which affects the proper and smooth functioning of other departments. Sankey diagram (Fig. 8) shows the process of material flow of output components from Workstation 1 to other departments. The thickness of the line represents the volume of material for each time point and the length of line represents the distance of transport.

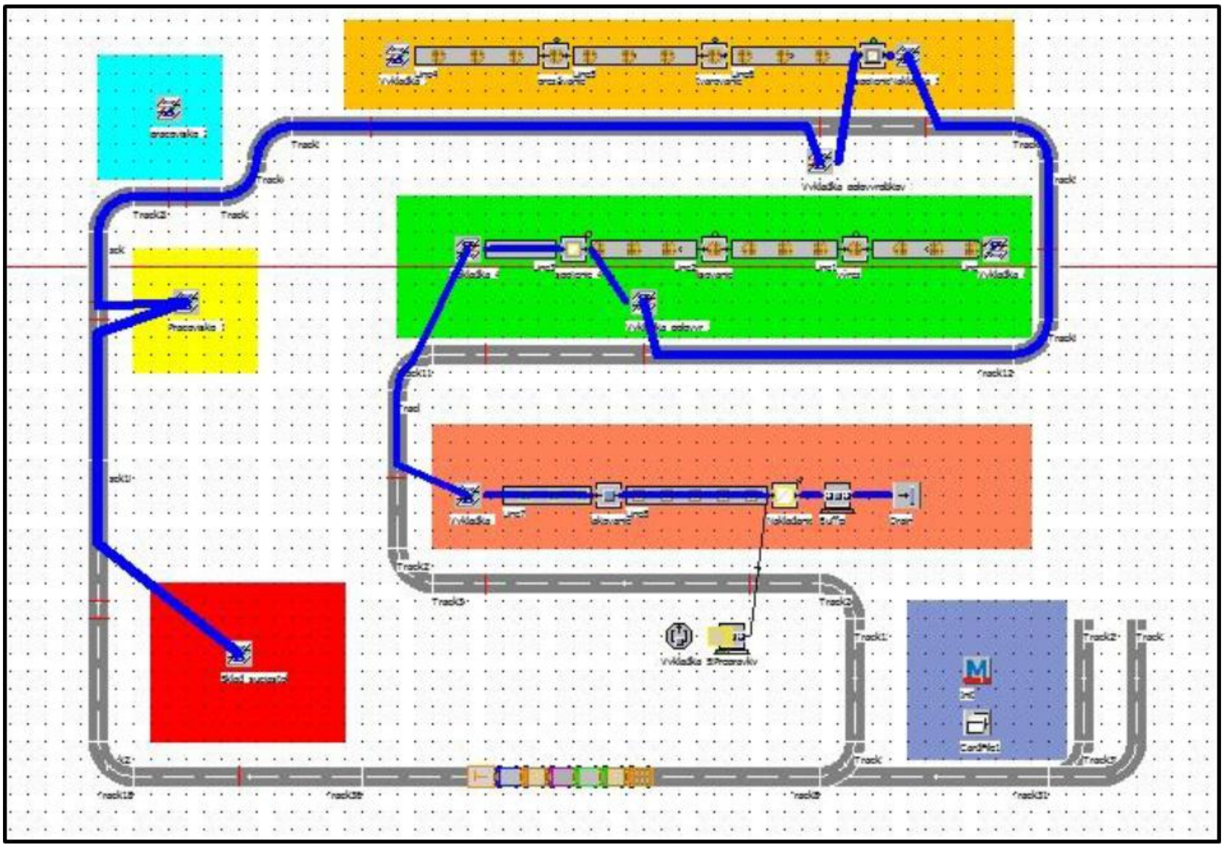


Fig. 8.
Sankey diagram of the material flow of output components from Workstation 1
Source: Authors

Four simulation experiments were carried out, which should serve to improve the simulation model and to improve processes within the monitored workplaces.

The simulation experiment no. 1 concerned the changes in the volume of input stocks in the Workstation 1. The monitored simulation model showed a large amount of unnecessary supplies at Workstation 1. The aim of the experiment no. 1 was to reduce these stocks by adjusting the imported quantity and also the capacities of respective storage containers were adapted. These changes contributed to increasing regularity in delivery of output components from Workstation 1, which affect the continuity of the functioning of other workplaces. The simulation experiment no. 1 was considered successful, it means, the changes were applied to the simulation model.
The simulation experiment no. 2 was aimed to reduce the speed of the conveyor belts at Workstation 3. The experiment no. 2 was focused on monitoring the performance of the model at a reduced speed of conveyor belts at the Workplace 3, as the performance graphs showed blocking the belts. Prerequisite for changes in the speed of conveyor belts was to harmonize interrelated processes at the workplace. Experiment no. 2 had no affect at the movement of material flow between workplaces and despite of this performed change increased a coherence of activities at Workplace 3. Therefore, the changes were applied to the simulation model.
The simulation experiment no. 3 detected changes at speeds of conveyor belts at the workplace 4. The low performance of the machine at the Workplace 4 was causing excessive accumulation of parts in the container, which weakened the performance of the whole production process. Therefore, another experiment no. 3 was carried out, in order to increase the production of the entire production process by increasing the speed of the conveyor belts at the Workplace 4.
The simulation experiment no. 4 examined the state for the situation when two sets of carriages were created. By creating two sets was shorten the duration of one circular route because one set of trailers did not stop at all workplaces along the circular route, just on those which it supplies. The shortened duration of circular route had affected the continuity of production processes, which has been achieved by improving the simulation model according to the previous simulation experiments no. 1, 2 and 3.

5. Conclusion

The importance of AGV systems within logistics will continue to grow. Their role in maintaining of supply, transport and various service activities will become more and more dominant and irreplaceable. Currently the method of computer simulation has major importance for research and operation of AGV systems. For its successful application, it is needed to create a suitable simulation model and to use the appropriate simulation software. AGV systems operators should however be aware that the importance of computer simulation does not end by launching of the whole system. On the contrary, they should try to use simulation model not only during the regular operation of the entire transport system. This is particularly the verification of various changes in the process of transport, the development of dispatching plans and the performance analysis and capacity utilization of the transport system. In consequence of above-mentioned facts, the computer simulation becomes routine work tool and decision-making tool.

Acknowledgements

This work is a part of these Slovak projects VEGA 1/0258/14, VEGA 1/0063/16, KEGA 006STU-4/2015, KEGA 018TUKE-4/2016.

References

Fazlollahtabar, H. 2016. Parallel autonomous guided vehicle assembly line for a semi-continuous manufacturing systém, *Assembly Automation* 3(36): 262-273.
Ficzere, P.; Ultmann, Z.; Török, Á. 2014. Time–space analysis of transport system using different mapping methods, *Transport*, 29(3): 278-284.
Huo, K.G.; Zhang, Y.Q.; Hu, Z.H. 2016. Research on scheduling problem of multi-load AGV at automated container terminal, *Journal of Dalian University of Technology*, 3(56): 244-251.
Ishizuka, Y.; Hidaka, K. 2015. Motion control for an automated guided vehicle in the factory with a stereo camera, IEEJ Transactions on Industry Applications 8(135), 836-846.
Jin, J.; Zhang, X. H. 2016. Multi AGV scheduling problem in automated container terminal, *Journal of Marine Science and Technology* 1(24), 32-38.
Kumar, R.; Haleem, A.; Garg, S.K.; Singh, R.K. 2015. Automated guided vehicle configurations in flexible manufacturing systems: A comparative study, *International Journal of Industrial and Systems Engineering*, 2 (21), 207-226.
Molnár, V. 2012. SAP warehouse management system for a warehouse of auxiliary material in the selected company. In *Proceedings of the Carpathian Logistics Congress*, 1-6.
Strohmandl, J. 2014. Use of simulation to reduction of faulty products, *UPB Scientific Bulletin, Series D: Mechanical Engineering*, 76(3): 223-230.
Szendrő, G.; Török, Á. 2014. Theoretical investigation of environmental development pathways in the road transport sector in the European Region, *Transport*, 29(1): 12-17.
Štusek, J. *Řízení provozu v logistických řetězcích*. 2007. C. H. Beck, Czech Republic.

Tomková, E.; Husáková, N.; Strohmandl, J. 2015. Possibilities of economic efficiency solution in road haulage. In *Proceedings of the 19th International Conference on Transport Means*, 694-697.
Ullrich, G. 2015. *Automated Guided Vehicle Systems*. Springer Heidelberg, Germany.
Wang, M.; Zhou, Y. 2016. Scheduling for an automated guided vehicle in flexible machine systems. In *Proceedings of the Winter Simulation Conference*, 2908-2916.

APPLICATION OF TRACKING TECHNOLOGIES IN THE POSTAL SYSTEM

Libor Švadlenka[1], Momčilo Dobrodolac[2], Mladenka Blagojević[3]
[1] *University of Pardubice – Jan Perner Transport Faculty, Pardubice, Czech Republic*
[2,3] *University of Belgrade – Faculty of Transport and Traffic Engineering, Belgrade, Serbia*

Abstract: This paper presents the possibilities of tracking technologies application in the postal systems. There could be the postal items, vehicles, production tools and employees tracked in the postal system. Based on the tracking object and the way the collected data are used, these technologies could lead to a corresponding efficiency control of the business process and higher quality achievements in the postal company. For the tracking purposes it is possible to use various technologies. In this paper the implementation of Radio Frequency Identification (RFID) is illustrated.

Keywords: tracking, postal technology, efficiency control, RFID.

1. Introduction

The postal network makes a biggest logistic system globally. The traditional postal services have a significant role in the global economy even in the modern society characterized by information technologies. For example, when people communicate and buy through the Internet, goods must be delivered to the purchaser in physical form where a corresponding postal infrastructure is certainly necessary. In this case postal service could be seen as a connection between virtual and physical world.

For decades, national postal operators were the only providers of postal services by keeping a monopoly in this area. However, today's postal market is rapidly transforming to adapt to the modern world market characterized by liberalization, deregulation, globalization and technological progress. In the postal industry, these developments bring increased competition, changed customer behavior as well as a possible reduction in the volumes of shipments. In parallel with these market changes, a substitution by other communication media should be mentioned, as well as increased efficiency standards and requirements for improved performance at all stages of the postal process.

A possible solutions for these challenges is the use of modern technologies in the postal process. One of the mentioned is RFID (Radio Frequency Identification). The introduction of RFID systems in the postal sector can bring significant savings and competitive advantages while enhancing the quality of operations. It is very important to notice that while the costs of prevention and measurements grow then the costs of failure in business or the payment of fees for exceeding the time limits or shipment losses decrease.

Harrop and Holland (2008) in their report estimate that the global market for RFID systems, including tags, in the postal sector will be $2.5 billion in 2018. It could be much bigger if current efforts to tag individual items gain widespread acceptance. In due course, over one trillion postal items will be tagged yearly, making this the second largest application of RFID in the world after the retail supply chain.

In this paper we analyze the possible points in the postal process where RFID technology could bring the higher efficiency and quality. In the second section we first explain the basic concept of RFID technology. Then in the third section we scrutinize the possibilities of RFID implementation in the postal system. These possibilities could be divided in groups depending on what is tracked. In this paper we make the following groups: tracking of postal vehicles, production tools, employees and postal items. Finally, we conclude with the benefits expected by the implementation of RFID technology.

2. RFID technology

Automatic identification, or auto ID for short, is the broad term given to a host of technologies that are used to help machines identify objects. Auto identification is often coupled with automatic data capture. That is, companies want to identify items, capture information about them and somehow get the data into a computer without having employees type it in. The aim of most auto-ID systems is to increase efficiency, reduce data entry errors and free up staff to perform more value-added functions, such as providing customer service. There are a host of technologies that fall under the auto-ID umbrella. These include bar codes, smart cards, voice recognition, some biometric technologies, optical character recognition and radio frequency identification (RFID).

Radio Frequency Identification (RFID) is a generic term for technologies that use radio waves to automatically identify people or objects. There are several methods of identification, but the most common is to store a serial number that identifies a person or object, and perhaps other information, on a microchip that is attached to an antenna (the chip and the antenna together are called an RFID transponder or an RFID tag). The antenna enables the chip to transmit the identification information to a reader. The reader converts the radio waves reflected back from the RFID tag into digital information that can then be passed on to computers that can make use of it.

[1] Corresponding author: libor.svadlenka@upce.cz

RFID system consists of a tag, which is made up of a microchip with an antenna and an interrogator or reader with an antenna. The reader sends out electromagnetic waves. The tag antenna is tuned to receive these waves. A passive RFID tag draws power from field created by the reader and uses it to power the microchip's circuits. The chip then modulates the waves that the tag sends back to the reader and the reader converts the new waves into digital data.
The most common applications of RFID technology are tracking goods in the supply chain, reusable containers, high value tools and other assets and parts moving to a manufacturing production line. RFID is also used for security (including controlling access to buildings and networks) and payment systems that let customers pay for items without using cash. The application in the postal industry is significant as well.
According to research conducted in 2015, the total RFID market is worth $10.1 billion, up from $9.5 billion in 2014 and $8.8 billion in 2013. This includes tags, readers and software/services for RFID cards, labels, fobs and all other form factors, for both passive and active RFID. Forecast predicts rise to $13.2 billion in 2020.

3. RFID in the Postal Sector

It all started with active tags being put in a random sample of postal packages, including letters, from many countries to assess the level of service so cross charges between the postal services of different countries could be equitable. This is still done to this day. However, RFID is now used by postal and courier services for many other purposes.
The potential market for RFID in the postal and courier service is second only to that for the retail supply chain as shown below (Figure 1).

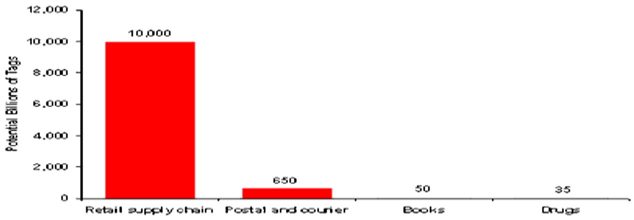


Fig. 1.
Potential global market in billions of RFID tags yearly
(Source: Das and Harrop, 2015)

RFID can facilitate the perfect product recall and postal companies are fitting RFID labels on cases and pallets of consumer packaged goods at retailers, because it increases availability and thus sales and reduces costs, valued at billions of dollars yearly for that industry. RFID is so crucial to the future of courier and postal services that UPS (United Parcel Service) has invested in four RFID companies just to be first to see the future.
The global market for RFID systems, including tags, in this sector will grow extremely rapidly to be $3 billion in 2016 (Figure 2).

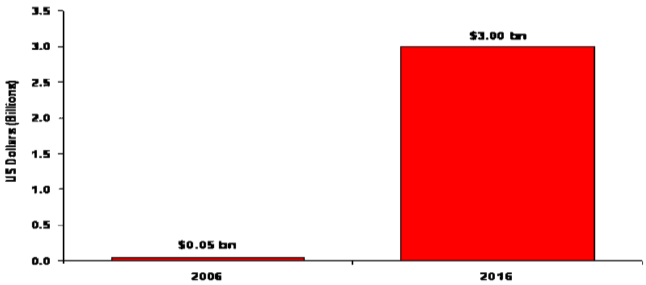


Fig. 2. *The global market for RFID systems*
(Source: Das and Harrop, 2015)

Today, the percentage of tags by value that are active (i.e. with a battery to increase range or manage sensors or encryption) is around 20%. In the postal and courier service the percentage by value is higher because most of the initial work is done on vehicles, trailers and conveyances but that will change. As the really high volume tagging of postal items commences, the percentage of spend on active tags in the postal and courier service will drop to a figure below the average for all RFID. Indeed, the new passive tags with enhanced performance, notably improved range, will take market share from active tags in existing applications. Nonetheless, the market for active tags in the postal and courier service will continue to rise. It will remain a worthwhile and profitable activity for suppliers (Das and Harrop, 2015).
The global market for RFID systems, including tags, in this sector will grow extremely rapidly to be $2.5 billion in 2021. It could be much bigger if current efforts to tag individual items gain widespread acceptance. In due course, over one trillion postal items will be tagged yearly, making this the second largest application of RFID in the world after the retail supply chain. Detailed ten year forecasts are given plus a full explanation of the technologies. In detail, there are over 40 new case studies of RFID in action in the postal and courier service in North America, Europe, the Middle East

and East Asia. The major breakthroughs that will provide future success are discussed. Postal services ignoring this accelerating change will become uncompetitive and suppliers missing out will regret it. RFID is an idea whose time has come in postal, courier and high volume light logistics. In the past, RFID has been used for little more than the evaluation of postal performance, using tags in a small percentage of letters, and the tracking of a small number of conveyances and vehicles. From the International Postal Corporation now monitoring mail flow with RFID in over 50 countries to Saudi Post tagging postal boxes, the big innovations are now happening. Saudi Post and the electronics giants in Korea are among the great innovators in this area. Within Deutsche Post, another RFID innovator, DHL has done successful trials of RFID labelling individual items to improve service and reduce cost and has tested market prices against the possibility of tagging all its one billion items yearly. This is the stuff of competitive advantage.

3.1. Vehicle tracking system

As we mentioned, postal vehicles, as a part of the postal infrastructure, can be covered by tracking technologies. In that sense, an efficient vehicle tracking system is designed and implemented for tracking the movement of any equipped postal vehicle from any location at any time. Purpose of the vehicle tracking system is multiple. The emphasis is on monitoring the characteristics of vehicles which are important for the smooth running of postal flows. Some of these features are vehicle tracking, vehicle's access control and inventory.

Vehicle tracking **-** in the case of vehicles movement between predetermined and fixed destinations it is possible to automate the monitoring of vehicle's movement without human influence. On each vehicle is fixed tag. In the moment of arrival and departure on the destination the reader on a given point writing to tag data of arrival and departure time. When the vehicle is returned to the destination point these data is automatically removed during the passing of the vehicle through the entrance of the building, through the antenna and the reader.

Vehicle's access control **-** means control such as access to a reloading point, access to parking, vehicle identification in the process of refueling, vehicle identification during transport and so on. In the case of controlling parking, RFID tag is placed on the vehicle or on the driver and reader is located at the entrance of the parking space. Arrival of the vehicle causes reading information located in the transponder, processing this information and providing of appropriate command.

Inventory **-** reliable and accurate data on the status, condition and tire positions are one of the most important factors for successful management of operational fleet costs at post offices. The usual situation is that the tires indicate by incision or marks with waterproof markers. Keeping records of each tire, including the place where it is set, date of purchase, date of retreading, amortized cost, etc., is done by manually collecting, typing in the document and the manual data processing. This process is susceptible to errors and possible manipulations. A system for keeping records of tires based on RFID technology consists of the following components:

- Miniature radio frequency tag that has pre-registered the unique ID code of twenty characters. There is no possibility to find the two tags with the same ID code. The tag is fixed to the outer tire, on the side of the tire. Fixing is done by simply pasting flakes over the tag. In this way, each tire is uniquely defined by the ID code. Basic characteristics of the tag is light weight, work in extreme conditions and communication wirelessly with the handheld reader for updating data,
- Handheld reader for automatic collection and storage of data on each tire. ID code from the tag is wirelessly transmitted to a database that is in the handheld reader. For all the tires on one vehicle process takes a few minutes. In addition to the tire's ID codes, there are entered and vehicle's information, driver's information and so on. In the same way collects data of the tires in the warehouse and workshop. Data from the handheld reader is transmitted via the communication to a computer for further processing,
- A computer that enables further processing of data on tires obtained from the handheld reader,
- Software that is installed on computer and uses for the collection, analysis and reporting.

3.2. Production tools monitoring

Controlled delivery and collection of postal items from post boxes **-** using the RFID system it is possible to automate the process of monitoring collection of items from post boxes. On each mailbox a tag with clearly inscribed ID code is placed. Bags for collection are equipped with micro-reader with a memory sufficient for registration and storage of alleged ID codes from tags on the post boxes. A reading of contents from the micro-reader is performed at the place where the items are collected. In this way, automatically is recorded the ID of each post box which was read during the collection of items.

The Wasel project, implemented by the Saudi Post, in an attempt to transform and improve business before privatization and provides the use of smart mailboxes equipped with RFID chip. The role of the chip is to report to the courier equipped with handheld reader whether address is appropriate. Also, the idea of this project is the possibility of elimination of users need to go to the post office when sending items. Instead of that, aim is to perform dispatch through electronic (smart) mailboxes.

After participating in the first phases of an ongoing project using active RFID tags to monitor the performance of Saudi Arabia's postal service, Saudi Post is rolling out RFID based mailboxes for citizens across the kingdom. This rollout is part of an overall IT and service upgrade that includes an active RFID based system to monitor quality at the nation's mail sorting centers.

Each of the 10 million mailboxes that will be installed at homes in Saudi Arabia is fitted with a passive ultrahigh frequency (UHF) EPC Gen 2 RFID tag that uniquely identifies it. Postal carriers employ handheld reader to identify the mailboxes before slipping letters into them (Figure 3). After a letter is inserted into a mailbox, the tag is read once more so that Saudi Post's system can verify when mail was delivered to that particular home. The handhelds, containing GPS and wireless data communication modules, are used to provide real time updates to managers regarding postal carriers' locations and activities.

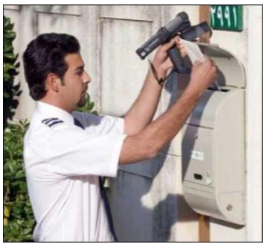


Fig. 3.
Saudi postal carriers with handheld reader

Before the RFID based mailboxes were installed, Saudi citizens picked up their mail at post offices, where they could also take care of banking, the payment of utility bills and other tasks. Homes did not have mailboxes at all, and the country lacked a single, unified addressing system. That limitation has resulted in various entities, such as electric companies or private logistics firms, creating their own grids and zones and utilizing different addressing systems for the same location and, thus, causing confusion and delays for the delivery of packages and mail. To rectify this problem, the government run Saudi Post implemented uniform addresses simultaneous with the planning of the RFID based mailbox project.
To date, millions of steel government owned mailboxes bearing RFID tags have been installed across multiple cities, as part of the so called Wasel project (*wasel* is the Arabic word for "reachable"). The mailboxes, which resemble those widely used in Europe, are attached to the exterior walls of homes and buildings (Figure 4).

Fig. 4.
Saudi Post mailbox with an embedded EPC Gen 2RFID tag

The tags which have 96 bits of programmable memory and function at 915 MHz are embedded in a plastic housing attached to the steel mailbox, manufactured by a local company. The housing keeps the metal from interfering with the tag, and also protects the tags from Saudi Arabia's sand, as well as windstorms and other harsh weather. In addition to providing the intelligent mailboxes at homes, Saudi Post is continuing to offer post office boxes to its citizens. The postal carrier is leaving it up to each individual to decide if he or she wants to use both systems, or to switch completely to home based delivery.
Saudi Post is planning a pilot to use the RFID mailboxes together with bar coded ID numbers printed on mailed items, in order to monitor the performance of the country's mail sorting centers. The monitoring system currently features semi-active RFID tags attached to regular mail test letters.
The letters are mailed from random locations and are tracked at key postal sorting centers. Saudi Post also has three mobile reading systems that can be set up in any facility in which it wants to track mail for quality measurement. Each mobile system contains a special computer that operates as a controller, as well as an interrogator and two units for exciting the tags. The units connect to Saudi Post's main servers via a GSM connection and the carrier moves them around as needed to conduct quality tests.
In the new pilot Saudi Post is utilizing the infrastructure already set up to track a total of 500 bags of secure government mail carrying semi-active tags. The entire system and the tags are provided by Lyngsoe Systems. Each piece of government mail in the sack is printed with a unique ID number in bar code form, enabling Saudi Post to know which items are in a particular bag. As part of the pilot, the mail carrier plans to expand the reader infrastructure to three additional postal sorting centers.
Once the government mail is delivered to the RFID based mailboxes, and after a letter carrier has scanned the mailbox tag, the information will serve as an electronic proof of delivery receipt.

The system's main benefits are its ability to ensure that the correct mail is delivered to the proper mailbox, and to serve as proof of delivery for registered and official government mail. If the test of semi-active tags on sacks of mail becomes an ongoing project and is used together with the RFID based mailbox system, Saudi Post will also be able to track the time required for express home deliveries.

RFID control over roll containers **-** more than 600 RFID portals have been mounted in Swiss Post's postal and logistic centers to give the post complete control over their 70,000 roll container assets and their flow.

Fig. 5.
RFID tag for roll containers

Apart from the RFID tags on the containers, the fully integrated solution also utilizes barcodes and interfaces to other IT systems to provide end-to-end, track-and-trace of containers as well as onboard mail trays. Destination barcodes on mail trays are registered as consignments within individual containers using a unique automated nesting solution.

Swiss Post has a strategic goal of consistently meeting its own ambitious targets for customer satisfaction. Efficiency is the key, making heavy use of container and tray-based automated logistics, to handle:

- 2.4 billion letters,
- 100 million parcels,
- 70,000 roll containers.

Swiss Post has defined its own core values as "reliable", "value-enhancing" and "sustainable." To minimize operational costs, eliminate manual process, improve quality and logistics, it wanted to be able to identify and track all its containers and the items they contain.

Lyngsoe Systems won a tender to provide a new material management solution to provide Swiss Post with a complete inventory and flow overview system. The solution installed is advanced, fully automated and RFID-based comprising over 600 Quick Mount RFID portals at 47 sorting centers around the country, able to read passive EPC global Gen2 RFID tags attached to roll containers. The system also uses barcodes on mail trays that interface with other IT systems to provide end-to-end track and trace. Swiss Post achieved the following benefits:

- 100% visibility for roll container flow,
- Real-time track and trace data,
- Substantially reduced costs.

Tote boxes **-** UPS is a follower in RFID. The company began a series of pilot tests in 2004 on both its package delivery business and its supply chain solutions business, which serve many customers who must comply with upcoming RFID mandates. In one trial passive RFID tags are replacing bar codes on reusable fibreboard tote boxes used to shuttle packages through UPS's automated facilities. The objective is to extend the life of the tote boxes and to reduce the read-failure rates of the barcodes, which tend to wear off over time. In another pilot, RFID tags have been attached to UPS trucks in an effort to monitor cost-effectively vehicle activity moving on and off the property at three different locations.

Locking valuable bag **-** postal bags are often tagged with active or passive RFID tags to keep track of them. The Italian Postal Service has been a leader in this and other uses of RFID in the postal service. The problem of insurance of valuable bags can be enhanced by using the RFID system. On the inside of the bag is placed mechanical lock. Since such a mechanical lock can be easily robbed, RFID system provides complete mechanical and electronic coded protection of the possible ways of unauthorized unlocking. Unlocking is performed by mechanical key with a miniature radio frequency tag. The device inside the bag recognize ID code and unblock the mechanical lock and allows unlocking. Tag can include numerous combinations which the reader recognizes and on the basis of which allows the unblocking or blocking of a mechanical lock. One of the most important feature of this system, thanks to the technology of encryption, is that code in the tag changes dynamically every time when the key with tag brings closer to lock. At the same time provides a method of blocking and unblocking (Harrop, 2005).

Also, money transfer and insurance of deposit transactions can be raised to a higher level using the RFID system. Each bag of money contains a fixed tag, which reads on the depository machine. When the ID code from the tag is authorized, unlocks the space for the money. The client puts a bag with money in the slot and again starts ID code reading. If the ID code is correct client gets printed receipt.

3.3. RFID personnel and people monitoring

People access control, monitoring and attendance tracking belong to most demanded RFID applications. RFID based access control and monitoring systems are typically used for granting access or control the people attendance to office, enterprise, work place, car park, school, library, hotels, events and exhibition areas as well as for tracking employee time for payroll, safety, production and maintenance needs.
RFID based access control system can provide an easy and efficient solution for enabling access to only authorized employees. RFID embedded cards are being used for identification of authorized person to allow or deny access to restricted area.
Access control points can be doors, turnstiles, parking gates, elevator or other physical barriers with embedded RFID readers and antennas. The typical RFID tag can be a contactless smartcard, key fob, wristband or smart phone with NFC UHF sticker. The ID of a tag is verified against the access control list and the IDs access rights.
RFID solution at work places is ideal for a wide range of industries and businesses where hourly and salaried employee time is tracked, including manufacturing, warehouse and distribution, healthcare, retail, professional and medical offices, government, and educational agencies. RFID could be very useful in control over lost time and productivity, which can have a significant impact on the company’s profitability.
Data collected can be further used for work efficiency improvements and work flow optimization. The workers performance can be evaluated and compared, e.g. how many products a worker created within given time. This information can be used for work flow and methods optimization, evaluation, experience sharing and staff motivation.
RFID time and attendance systems automate employee time and attendance tracking improve productivity and eliminate costly payroll errors and thus reduce the time required to process employee time and attendance. Tracking employee time and attendance can be fast and simple with the RFID. Each employee is provided with a unique RFID badge. As the employee passes the RFID badge near the RFID reader/RFID gate, the RFID reader records the time of entry or exit. Data is downloaded on a scheduled or periodic basis, automatically delivering accurate time and attendance records (Roth, 2006).
Working hours recording terminal device provides accurate records of employees arrivals and departures from the company. Abuse by the employees can be reduced to the minimum by placing the network video camera to surrvey the spot arround the RFID readers. Video camera provides snap-shot of employees checking in or out. Employees check in when arriving to the work and check out when departuring by placing their ID card in front of the appropriate terminal device reader (CHECK IN or CHECK OUT). While checking in or out, employee can hold his/her card in protective foil or wallet. The card doesn't have to be taken out in order to be detected by the RFID reader.

Fig. 6.
Terminal device reader (CHECK IN or CHECK OUT)

ID card usually contains printed company's trade mark, owner's basic data and his/her photo, so the card provides not only electronic but also visual identification of the employee. ID card is equipped with re-writable memory which can be used for additional functions system provides (for example paying in company's restaurant). Employee's departure from the company during working hours can be managed in different ways. We suggest that employee reports to his/her superior which then decides whether employee can leave the company. Depending on the decision, superior then issues electronic approval, using his/her PC. Employee checks out when leaving and checks in on the return.
Turnstiles are placed on the gates for access control and passage records. They allow single person passage only. They can be equipped with RFID card readers, bar code readers, or both, as well as the coins and tokens acceptor. The turnstiles can be managed by external controller. Existence of separate reading devices for arrival and departure recording and turnstiles on the entering gate enables anti-pass back protection.

Fig. 7.
Turnstil

There are several different technologies used for card-based access control systems. Magnetic stripe cards store secure information encoded on a magnetic strip. By sliding the card through a special reader, an employee can gain entry to specific buildings and designated areas. Another highly popular method utilizes proximity (or RFID) card technology. With proximity cards, the information is embedded in the card, and the cardholder must simply waive the card within range of a card reader. The system can be designed so that specific workers are able to gain access to certain buildings and areas that require authorization. When it comes to controlling access to computers and networks, smart cards are an excellent option. Typically, these cards contain information on a smart chip embedded into the card. The employee inserts the card into the computer in order to log in and gain access to the company network. Such technology is often used for companies and corporations where workers must log in remotely. This allows employees from various locations to access the same network (FlexiRay, 2016).
Besides cards, very interesting solution is RFID chip implanted under one's skin (Fig. 8). The first reported experiments with an RFID implant were carried out in 1998 by the British scientist Kevin Warwick. His implant was used to open doors, switch on lights, and cause verbal output within a building. After nine days the implant was removed and has since been held in the Science Museum (London). This kind of human identification is further developing even today, despite a possible moral dilemmas about this process.

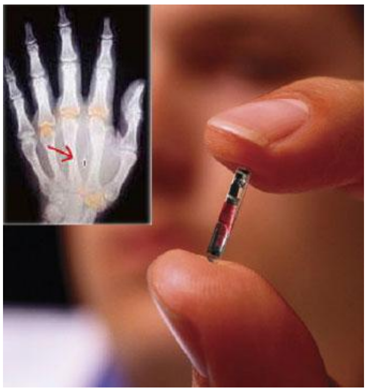


Fig. 8.
FRID tag under the human's skin
(Source: "Michael" Journal, 2016)

3.4. Shipment tracking

Shipment tracking is the process of localizing shipping containers, letters and parcels at different points of time during sorting, warehousing and delivery to verify their provenance and to predict and aid delivery.
Shipment tracking developed historically because it provided customers information about the route of a shipment and the anticipated date and time of delivery. Mail tracking is made possible through certified mail and registered mail, additional postal services which require the identification of a piece of mail to be recorded during various points of delivery, so that the sender can obtain a proof of delivery and the receiver can predict the time of delivery.
By using the service of tracking the item, a customer may get the information on date, time, place and status of their item from the moment of its entering the system. Each item in the system has its own identification (reception) number received upon posting.

3.4.1. RFID Postage Stamp

RFID technology is the future in improving the mail delivery. It is obvious that this technology will be the standard in marking parcels, especially as this technology has an increasing decline in the cost price tags (chips) and accompanying infrastructure equipment for RFID recording. The model of RFID Postage Stamp aims to initiate the implementation of the RFID technology on the basis of the symbiosis of traditional postage stamp and RFID tag which should mark the shipment and provide its complete Trace&Track service.

High-tech stamps containing radio frequency identification (RFID) chips are likely to replace the barcodes printed on letters and packages to sort and process mail. In due course, over one trillion postal items will be tagged yearly, making this the second largest application of RFID in the world after the retail supply chain. That may occur already around the year 2020. Postal services and shipping companies are already using RFID to grant access to secure areas, measure mail delivery performance and track vehicles.

In terms of programmable RFID postage stamps user can attach a stamp without a predetermined postage to an article to be mailed. The stamp has a top layer having a visual display, middle layer having an electronics layer, and a bottom layer having an adhesive layer. The stamp is encoded such that the visual display of the stamp is altered to indicate a state of the stamp. Postage of the item is determined by a postal authority worker and payment is authorized using the unique identifier. This eliminates the need for the sender to have any personal interaction with a postal worker to ship an article and eliminating the need for the sender to estimate postal cost prior to the article being received at the postal office. Altering the adhesive layer provides safe removal of the affixed stamp which can then be reused.

A system and method for postage payment utilizes passive RFID tags as postage “stamps”, with the amount of the postage automatically billed to a previously established customer account. The tags are stored in a separate stamp database and are “enabled” by linking the individual tag to a customer account. The use of the RFID stamps eliminates the need for the customer to know the proper postage beforehand. The existence of a customer account with a proper return address reduces the likelihood of a dead letter. Also, a special category of stamps may be used for automatic reply mail. By virtue of using an RFID tag, the mailed item's progress through the postal delivery system may be tracked from dispatch to delivery.

3.4.2. Measuring letter performance with RFID tags

RFID (Radio Frequency Identification) is an alternative technology to barcodes for the identification of items. The main difference is that barcode information is captured by optical means (a barcode scanner) whereas the RFID information is captured via a radio signal. The captured information for the purpose of letter performance measurement is the same but the means are different. The main advantage of RFID technology is that it is easy to automate the data capture process compared to barcodes. Scanning barcodes is typically a manual process which makes it more labor intensive.

The absence of unique identifiers requires the implementation of a sampling methodology, where test letters are mailed according to a statistical model. The posting and delivery dates are recorded by trained people. This data only provides information about the time the test letter takes to complete its journey.

The inclusion of an RFID transponder or tag in the test letter makes it possible to track the item at specific locations, typically where mail changes responsibility from the sending post to the receiving post. RFID equipment at specific entrance or exit doors records the passage of these tags without interfering with the operational process. The time and location is associated with the item details. This information undisputedly marks the ownership of the mail item that is necessary for measuring the letter performance of the postal operator responsible for processing the mail.

Posts have extended the technology in their facilities to gain a better understanding of their processes and make performance improvements where necessary. RFID is the enabling technology for measuring the performance of items that do not have a barcode such as letter mail. It largely avoids the problems of human error and cost of disorientation, obscuration and needing to read many barcodes at a time, phosphor dots, print issues, etc. This is why RFID is already used in the postal and courier service for secure access by people to vehicles and secure areas, secure access of vehicles to yards, location of parcels, conveyances, trailers and much more besides. RFID monitors the performance of the letter post, matches letters to postal boxes to prevent errors and records when and how much a sensitive package has been overheated in transit. In Sweden it is the basis of smart packages that record time of tampering and theft and leads to arrests.

The Universal Postal Union has been using passive ultrahigh-frequency (UHF) RFID tags based on the EPC Gen 2 air-interface protocol standard for monitoring the delivery times of letters in member countries, but there are no official standards for the use of RFID in the postal service. In general, most national postal agencies are utilizing passive UHF transponders to track parcels, bins, sacks and other assets used in their operations. For example, Correos, Spain's postal service, employs passive UHF RFID technology to pinpoint inefficiencies in its mail-handling processes. When it was installed in 2006, the system utilized 340 readers and 2,000 antennas installed across its 16 automated processing centers throughout the country, as well as four bulk mail-handling centers. Correos worked with a third party that uses a pool of 5,000 passive Gen 2 RFID labels to monitor the movements of letters through the mail delivery systems. By tracking the tagged mail's movements, the agency identified mail-handling procedures that it must improve to make speedy deliveries more consistent.

Radio Frequency Identification chips have been already deployed by postal companies in around 50 countries across the world to measure the quality of their services. The tags are attached to sample items. Their delivery process is monitored and is used to assess the efficiency of a postal service. But as costs drop and tags become smaller, RFID could be used for item-level tracking. Item-level tracking implies a massive deployment of RFID, potentially involving all the items sent. This would result in a close-to-zero risk of failed delivery. To make this possible, RFID chips would have to be cheap, tiny, easily available and based on common standards. High tech companies, like Hitachi or Motorola,

are currently working to make chips more affordable and functional. The size has already decreased so much that now experts do not talk of chips, but of “smart dust”. But interoperability remains a key concern. The European Commission launched a two-year project called GRIFS to build a global RFID standards forum. All stakeholders agree on the need of talking and finding common grounds.
There is even a postal RFID system that completely automates the whole process of mail delivery from accepting the package to classification and dispatching. It has been successfully tested in Korea. The new RFID system, developed by ETRI of Korea, aims to reduce costs, errors and tedious human intervention. It will provide a comprehensive electronic postal system with the potential to maximize mail package process capabilities while minimizing logistics cost.
It is difficult to estimate when RFID tagging of most of the courier and letter post will occur; however RFID labeled parcels, conveyances, vehicles and trailers are now very usual, with multiple benefits often being enjoyed. RFID is enhancing security and safety and removing tedious operations. Swedish Post has a parcel that detects and records tampering using RFID and other innovations abound, including RFID cards controlling driver access to postal vehicles and RFID enabled postal sorting equipment.

3.4.3. AMQM system for postal service quality measurement

The Universal Postal Union has paid special attention to traffic measurements and stimulates the postal operators by various measures to introduce advanced systems of measuring quality in providing postal services. Many postal operators have undertaken significant steps to increase the percentage of postal item delivery within a defined period of time, to reduce the terminal costs and to respond to the increased users' requirements. These authorities were the first to introduce the quality measurement system - AMQM (Automatic Mail Quality Measurement).
This system allows tracking of postal items "from start to end", i. e. from sender to receiver, and provide the postal authorities with the necessary activity with the aim of identifying and then also of eliminating bottlenecks in the phases of transfer and processing. The AMQM system records the difference between the actual and expected transfer speed of postal items in particular parts of the transfer process. This information is the basis for constant process of increasing the quality of providing postal services (Spajić and Sapina, 2007).
The basic elements of the AMQM system for quality measurement include:

1. Transponders,
2. Stations for reading/low-frequency antennas, uhf antenna grid and reading unit,
3. Local system for collecting data ldsc,
4. Central control system.

Post Norway is Norway’s national postal service, covering the entire country and its islands. Norway’s postal service needed to ramp up its technology-based systems to meet the need for visibility and real-time information on shipments. Its forward-looking policy has meant constant investment in an RFID based hardware and software infrastructure over the last 20 years, designed to support the best in customer services. Investment in an advanced RFID data capture infrastructure achieved the following:

- Real-time data on location and expected delivery of shipments,
- Full track and trace,
- Competitive advantage over other carriers,
- An increase in business measurable on the top line.

The geography and demographics of Norway pose special problems in terms of logistics. Recognizing the need to arrest falling revenues whilst increasing value, Post Norway began to implement an advanced portal infrastructure to generate data on the movements of items at a very early stage. Lyngsoe Systems has supported the carrier every step of the way to measure its domestic and international Quality of Service levels. The most recent significant investment was the installation of active/passive RFID portals across the country at no less than 340 locations (Lyngose Systems, 2016). Post Norway’s policy is to utilize Lyngsoe Systems' Automatic Mail Quality Measurements (AMQM) RFID hardware and Quality of Service Monitor (QSM™) software to take the provision of customer data to the next level. Benefits include:

- Top line business growth,
- Cost reductions,
- High quality of service,
- Improved logistics,
- Real-time data and visibility for customer shipments.

Post Norway is able to offer complete Track and Trace to B2B, B2C and private customers thanks to Lyngsoe Systems’ RFID portal infrastructure, track large load containers for carrying parcels and measure Quality of Service for domestic and international services. Lyngsoe Systems has provided a complete range of services from planning and design, through consultancy to installation over more than 20 years.

Post of Serbia is the winner of the award for AMQM – Enlargement of the system for automatic quality measurement as the best implemented project financed by the Fund for the quality of the Universal Postal Union since 2007. Transit time of the test-letter which included the transponder, is recorded through RFID equipment and Post of Serbia in an absolute leader of this segment in the region. The following chart presents the results of AMQM measurement system in the Post of Serbia for the year 2012 (Fig. 9).

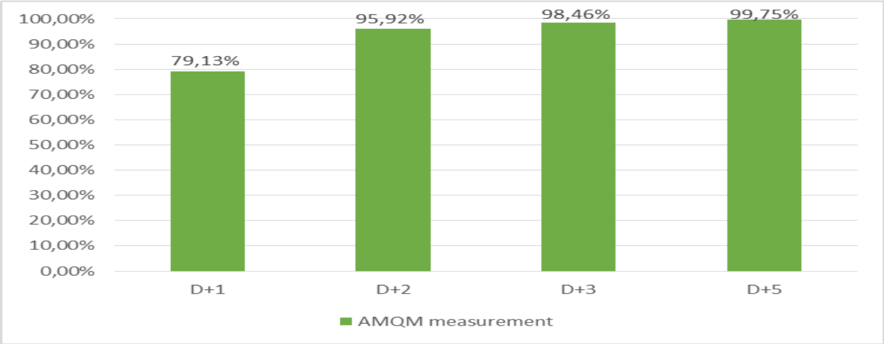


Fig. 9.
Quality level measured by AMQM system in 2012

The following graph shows a relationship between the level of quality specified by the regulatory body of Republic of Serbia (RATEL) and quality level measured by AMQM system (Fig. 10).

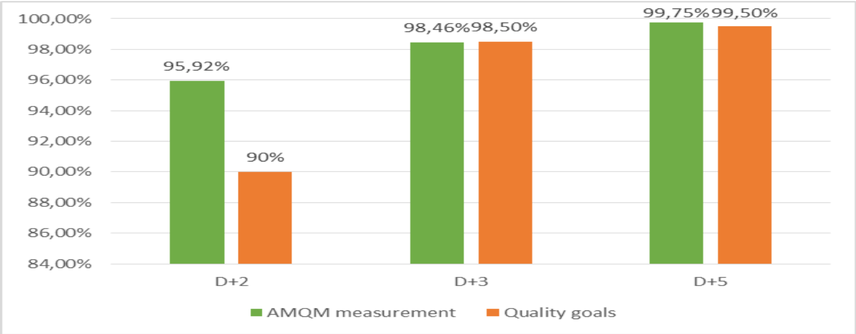


Fig. 10.
The relationship between required minimum level of quality and quality level measured by AMQM system for 2012

Looking at the results in the previous chart it is noted that the achieved results have exceeded goals set by RATEL, except for D+3 transit time.

4. Conclusion

The new material management system allows to always know where a mail is located, its destination and to identify bottlenecks in production or transport. It helps improve the level of quality of service and meet strategic targets including customer satisfaction.

Due to its diversity and flexibility RFID technology provides opportunities for improvement in all areas of human activity. It brings to accelerating and increasing of production efficiency, facilitating of monitoring in transport, eliminating the need for manual inventorying of warehouses and shops, control of pets and patients in hospitals and many other benefits in all fields where the identification and sharing of data is required.

The possibilities of using RFID technology are practically limitless. The information gathered by RFID technology provides making correct and timely decisions, and also, it can be expected that the application of RFID improve and optimize the engagement of the workforce, increase the efficiency of the supply system and reduce human errors and frauds and finally what is most important, it could bring to significant savings.

The development of new technologies many analysts saw as a threat to the postal sector; however, in practice it shows just the opposite. They create a fertile ground for the development of new postal services, quality and efficiency improvements. In this paper we precisely address these issues by illustrating the possibilities of RFID implementation in the postal company. We pointed out these possibilities in the following segments: vehicle tracking, production tools monitoring, personnel monitoring and shipment tracking.

Acknowledgements

This research was supported by the Czech Project CZ.1.07/2.3.00/30.0058 and the Ministry of Education, Science and Technological Development of the Republic of Serbia by the Project TR 36022.

References

Das, R.; Harrop, P. 2015. RFID Forecasts, Players and Opportunities 2016-2026. Available from Internet: <http://www.idtechex.com/research/reports/rfid-forecasts-players-and-opportunities-2016-2026-000451.asp>.

Harrop, P.; Holland, G. 2008. RFID for Postal and Courier Service 2008 – 2018. Available from Internet: <http://www.idtechex.com/research/reports/rfid_for_postal_and_courier_services_2008_2018_000129.asp>.

Harrop, P. 2005. RFID in the Postal Service. Available from Internet: <http://www.prisonplanet.com>.

Lyngsoe Systems. 2016. Available from Internet: <http://www.lyngsoesystems.com/en/solutions/postal-logistics/>.

FlexiRay. 2016. Available from Internet: <http://www.flexiray.com/rfid-applications/people-monitoring>.

"Michael" Journal. 2016. Global Control through the RFID Chip. Available from Internet: <http://www.michaeljournal.org/RFID.htm>.

Roth, P. 2006. Workplace Privacy Issues Raised by RFID Technology. In *Proceedings of the Privacy Issues Forum, New Zealand,* 10-16.Spajić, D.; Sapina, K. 2007. AMQM System for Measuring the Quality of Postal Services, *Promet-Traffic&Transportation,* 19(2): 129-137.

MODELING AND INVESTIGATING FREEWAYS AS SYSTEMS WITH VARIABLE CHARACTERISTICS: APPROACHES IN RUSSIA AND GERMANY

Anton Sysoev[1], Justin Geistefeldt[2], Semen Blyumin[3], Alexander Galkin[4], Pavel Saraev[5]
[1,3,4,5] Lipetsk State Technical University, Department of Applied Mathematics, Lipetsk, Russia
[2] Ruhr University Bochum, Institute for Traffic Engineering and Management, Bochum, Germany

Abstract: The increasing number of vehicles requires a more detailed investigation of road traffic systems on different layers – from city intersections on the microscopic level to transportation networks within a city, region or state on the macroscopic level. In this context, the analysis of freeway characteristics is of particular importance. A crutial component in this field is the capacity, which be calculated by using different approaches. The paper presents a comparative analysis to determine the capacities for freeways both in Germany and Russia. Usually, the capacity is defined as the maximum number of vehicleswhich can traverse a stretch of road per time unit in one or two directions under the prevailing road, traffic, and weather conditionsRecently, new stochastic concepts to estimate the capacity of a freeway were developed and applied in different studies. In this case, the capacity is regarded as a random variable whose features can be determined by analyzing the transition of traffic flow from fluid traffic conditions into congested flow. This event is usually referred to as a traffic breakdown. As every random process, the capacity here can be described by a distribution function. Anonparametric method to find parameters of this distribution is the Kaplan-Meier approach. It was found out that Weibull distribution best approximates empirical data. To model Weibull-distributed values correctly, it is necessary to construct bounds for the distribution function. Another problem highlighted in the paper is the interval characteristics for distribution parameters estimated using the Kaplan-Meier approach.

Keywords: mathematical modeling, variable structure systems, Weibull distribution, freeways.

1. Introduction

The comparison of classic and alternative approaches to model and to investigate freeway traffic flow is the major objective of the paper. Based on the assumption that the freeway segment as an element of a larger complicated system has a Poisson distributed incoming flow with a certain processing flow, we can use the one-channel classic queuing system to model it. To simplify the system of Kolmogorov's equations, which forms modeling formulas, the deterministic distribution of the flows mentioned above is applied. These theoretical ideas were taken into account while Russian and German National Guidelines were being developed. But the results obtained by applying them are not always realistic. It was established that the process of congestion formation at the bottleneck of a freeway segment is comparable with the analysis of samples that include censored data. The results received by Zurlinden (2003), Brilon et al. (2007) formed the base for freeway variable (stochastic) capacity understanding. The paper also presents the way to bound the function describing the distribution of breakdown probability (which is used to estimate the capacity), to avoid unrealistically small capacities for real-world applications. The estimated parameters of the Weibull distribution have to be bounded by confidence intervals. To find them, the idea of using pivotal function is applied.

2. Approaches to model freeways

A lot of researches describe various ways to model transportation systems in general and freeways in particular. For example, Rice and van Zwet (2004) proposed a method to predict the travel time needed to pass through a freeway section using a simple linear regression approach. This method is based on the combination of historical data and real time information. Chen et al. (2004) use principal curves to describe and analyze the interaction among freeway traffic flow variables and their joint behavior without any assumption on the functional forms. Many authors like Meldrum and Taylor (1994), Dharia and Adeli (2003), Codur and Tortum (2015) suggest using artificial neural networks and hybrid networks to model and further to estimate characteristics of freeway segments or the whole road. The conception of "black box" which underlies neural networks is a very perspective, but not the most common one. Actually average values of traffic flow characteristics within the freeway are only important, that is why the structure of a mathematical model to describe the object must be quite simple. Therefore, the queuing systems and queuing theory are very popular as a way to describe and research traffic systems and their main practically important characteristics.To define a queuing system, it is necessary to indicate the distribution of incoming flow, the distribution of service time and a service discipline. In contrast to the classical stochastic approach based on a Poisson distribution for the arriving process and some stochastic distribution for the explanation of the service time, the deterministic mechanism assumes to use a constant fixed arriving time for every request (or job, message) in a system and constant times for the service process. Though, there are many well-known service disciplines (cf. Ventzel, Ovcharov, 1983). For freeways, the FCFS (first-come-first-served) discipline is assumed to be the only applicable. The appropriate queuing system to describe freeway traffic flow, which is under consideration in this paper, is D/D/1, where D represents the deterministic distribution law and 1 shows that the system is considered as a single-channel system.

[1] Corresponding author: anton_syssoyev@mail.ru

The tendency to use variable structure systems to model freeways is devoted special attention to. Variable structure is understood here as a feature of existing unstable characteristics of a system which has a random distribution through the time and the amount of vehicles. In spite of classical deterministic approaches to estimate the capacity of freeways, which dominate both in Russian and German Guidelines, the systems with variable characteristics to investigate roads are becoming commonly used.

3. Russian and German criteria to detect the quality of the traffic flow

Comparable with the U.S. Highway Capacity Manual (HCM 2010) and the German Handbuch für die Bemessung von Straßenverkehrsanlagen (HBS 2015), the Russian National Guidelines (RNG 2012) focuses on the idea to estimate the performance of freeway segments by analyzing the volume-to-capacity ratio. In its first edition (1982), based on this measure of effectiveness, 5 levels of service (LOS) were defined. The new version contains 6 levels of service; table 1 gives the comparison for LOS as the criterion of the movement convenience for RNG and HBS.

Table 1
Thresholds of the volume-to-capacity ratio defining the Level of Service (LOS) on freeway segments

LOS	A	B	C	D	E	F
RNG 2012	< 0.2	0.2 - 0.45	0.45 - 0.7	0.7 - 0.9	0.9 - 1.0	> 1.0
HBS 2015	≤ 0.3	0.3 - 0.55	0.55 - 0.75	0.75 - 0.9	0.9 - 1.0	> 1.0

Source: Russian National Guidelines to detect the capacity of motorroads (version 2012), Handbuch für die Bemessung von Straßenverkehrsanlagen HBS 2015

The slight differences between the RNG and the HBS in the thresholds defining the LOS for freeway segments under certain traffic conditions can be explained by different theoretical models using different speed regulation regimes and different driving cultures. A brief overview of the RNG and HBS procedures and basic theoretical models for deriving design capacity values is given below.

4. Russian National Guidelines to detect the capacity of motor roads

The Russian National Guidelines to detect the capacity of motor roads (version 2012) include recommendations for calculating the capacity of different types of roads (dual highways, three-lane highways with an intermediate lane for reverse movement, freeways with four or more than four lanes), detecting the capacity of segments with unregulated intersections which are located inside and outside urban areas, estimating the capacity of merge points within different levels, calculating the capacity of signalized intersections; ways to estimate the capacity of freeway segments under certain conditions (as settlements located close to the highway, tunnels, roadside buildings, highlands). According to this document, there are several ways to estimate the capacity of freeway segments depending on the number of lanes, its location, geometrical characteristics, and other factors. All approaches are based on applying coefficients of reduction to the similar mathematical models with a simple structure.It should be mentioned that in terms of RNG, the capacity is calculated for both directions of a freeway segment, this fact must be taken into account to understand the design capacity values presented in RNG. For freeways with four (two in both directions) or more than four lanes, where the traffic flow has no uniform distribution through lanes, the capacity has to be determined for every lane separately considering the consistency of the flow, road, and weather conditions. In this case, the capacity of a freeway segment can be estimated as:

$$P = 2 \cdot (P_1 + ... + P_n), \tag{1}$$

where P is a practical capacity of a freeway segment, $P_1,...,P_n$ are practical capacities of lanes $1,...,n$, when the capacity for every lane is:

$$P_i = P_{\max} \cdot \prod_{j=1}^{5} \beta_j \tag{2}$$

Where; $P_{\max}$: the maximal capacity for the lane i (veh/h), β_j: the coefficients of reduction. These coefficients are responsible for the influence of merge points, geometrical parameters, the existence of an emergency stop lane, and the existence of suburban passengers transport. The tables presented in RNG give design values for the maximal lane capacity under different conditions, recommendations how to choose the correct set of reduction coefficients and their point estimates. Intermediate values (for Eq. 1 and 2) can be found using linear interpolation.

5. German Highway Capacity Manual

The latest edition of German Highway Capacity Manual HBS 2015 (Handbuch für die Bemessung von Straßenverkehrsanlagen) gives guidance for estimating capacities for types of road facilities. This version is the second

edition in which many theoretical results were adjusted. The HBS is divided into volumes describing analysis procedures of freeways, rural roads, and urban roads. Additionally, it contains a set of examples. The main assessment of basic freeway segments still follows the tradition of using deterministic capacities.
Design values for the estimation of freeway segment capacities according to HBS take into account prevailing road, traffic, and control parameters (in case of constant or variable speed limits). The design capacity values were derived by Brilon and Geistefeldt (2010) based on using van Aerde's (1995) model, which gives the traffic volume at the apex of the speed-flow relationship. According to van Aerde's model, the corresponding speed-density relationship is:

$$d(v) = \frac{1}{c_1 + \dfrac{c_2}{v_0 - v} + c_3 \cdot v}, \tag{3}$$

Where; $d(v)$: the traffic density at speed value v; c_1, c_2, c_3, v_0 : the parameters of the model. In unstable speed-flow conditions (a distinct gap between the fluid and congested traffic flows), the application of Aerdes's model (3) gives an unrealistic estimation for the practical capacity. To avoid this weakness the apex volume of the fitted speed-flow curve was compared with the 99th percentile of the distribution of all flow rates in the data sample. If the apex volume exceeded this threshold, the percentile value was considered to be the capacity estimation.
The assessment procedures for freeway segments in HBS use the following parameters, which influence the capacity: the percentage of heave vehicles, the location of the freeway inside or outside the urban areas, the number of lanes, the gradient (if it is greater than 2%), and the control conditions (speed restrictions, variable speed limits, special speed regime in tunnels, hard shoulder running). The HBS contains tables for design capacity values defined by the parameters above. Intermediate values can be found using linear interpolation.

6. Freeways as systems with variable characteristics: stochastic approach to estimate freeway segment capacity

The presented above approaches to estimate freeway segment capacity values given in the RNG and the HBS are deterministi, they deliver the same results for any segment under certain conditions, but this is not exactly the situation which occurs in reality. Under the same conditions the capacity values may vary because of factors with random nature (such as accidents, work zones, drivers' behavior and others). The gaining popularity approach to define freeway segment capacity as some stochastic value is given further. It operates with censored data analysis.

6. 1. Reliability Life Data Analysis for estimation the capacity

Van Toorenburg (1986) proposed to use models for censored data to identify the probability distribution function for modeling freeway capacity. In this approach, the traffic data is divided into “uncensored” and “censored” intervals. An interval is classified as “uncensored” if it contains an observation of the capacity. Van Toorenburg as well as Minderhoud et al. (1997) assumed that the capacity is observed whenever there is a queue on a freeway caused by a bottleneck. According to this, observations during both fluid and congested traffic are included in the capacity analysis. Due to the “capacity-drop” phenomenon (cf. Banks, 1990 and Hall and Agyemang-Duah, 1991), however, the capacity during congestion differs from the capacity before a breakdown. Thus, it is more appropriate to include only those values measured during fluid traffic conditions (cf. Zurlinden, 2003). If so, an interval i is classified as “uncensored” if the observed volume q_i causes a breakdown of traffic flow, thus the average speed drops below a specific threshold in the next interval i+1. The breakdown volume q_i is regarded as the momentary capacity of the facility. If traffic is fluent in interval i and remains fluent in the following interval i+1, this observation is classified as “censored”, which means that the capacity in interval i is greater than the observed volume q_i.
A nonparametric method to estimate the distribution function based on samples that include censored data (it is well known from lifetime data analysis applications) is the so-called “Product Limit Method” (PLM) by Kaplan and Meier. Based on this approach, the survival function $S(q)$ can be estimated by:

$$S(q) = \prod_{i:\, q_i \le q} \frac{k_i - d_i}{k_i}, \; i \in B, \tag{4}$$

Where; q: a flow rate (veh/h), q_i : a flow rate in interval i (veh/h), k_i: a number of intervals with the flow rate of $q \geq q_i$, d_i: a number of breakdowns at a flow rate of q_i, B: a set of breakdown intervals.
The capacity distribution function $F_c(q)$ is the complementary of the survival function:

$$F_c(q) = 1 - S(q) = 1 - \prod_{i:\, q_i \le q} \frac{k_i - d_i}{k_i}, \; i \in B. \tag{5}$$

The product within this equation is calculated over all observed time intervals i with a traffic volume $q_i \leq q$ that were followed by a traffic breakdown. Usually, each observed breakdown is used as one q_i-value, so that d_i is always equal to

1. The distribution function will only reach a value of 1 if the maximum observed volume is an uncensored value (i.e. a breakdown was following). Otherwise, the distribution function terminates at a value of $F_c(q) < 1$, where q is the maximum volume of an uncensored observation.

For a parametric estimation, the function type of the distribution must be predetermined. The distribution parameters can be estimated by applying the Maximum-Likelihood technique. For capacity analysis, the Likelihood function is:

$$L = \prod_{i=1}^{n} f_c(q_i)^{\delta_i} \cdot (1 - F_c(q_i))^{1-\delta_i} , \tag{6}$$

Where; $f_c(q_i)$: the statistical density function of the capacity c, $F_c(q_i)$: is cumulative distribution function of the capacity c, n: is a number of intervals, $\delta_i = 1$, if interval i contains an uncensored value, and $\delta_i = 0$, if interval i contains a censored value.

According to Brilon, Geistefeldt empirical comparison between different function types based on data samples from different German freeway sections revealed that freeway capacity is Weibull distributed (cf. Geistefeldt and Brilon, 2009). The Weibull-type capacity distribution function is:

$$F_c(q) = 1 - \exp\left(-\left(\frac{q}{b} \right)^{a} \right) \tag{7}$$

Where; $F_c(q)$ is a capacity distribution function, q is a flow rate (veh/h), a is the Weibull shape parameter, b is the Weibull scale parameter (veh/h).

The shape parameter a of Eq. 7 determines the variance of the distribution. According to Brilon and Geistefeldt (2010), the shape parameter of German freeway segment capacity distribution functions typically ranges between 10 and 22. The scale parameter mainly represents the systematic factors affecting freeway capacity, such as the number of lanes, the gradient, and the driver population.

6.2. Interval estimates of Weibull parameters

There are well-known standard assessment procedures to find point estimates of Weibull distribution function parameters. But the question how to detect confidence intervals for them was investigated skin-deep based on the assumption that they are normal distributed. It is not exactly correct. The interval notations for the parameters are presented below.

Let a and b are the shape and scale parameters respectively of a shape-scale distributed variate and $\hat{a}$ and $\hat{b}$ are the Maximum Likelihood Estimators of a and b. According to several authors (cf. Thoman et al., 1969, Lawless, 1974), the pivotal function can be used to estimate the possible distribution of shape and scale parameters. For example, Rinne (2009) give a detailed explanation based on the proving of theorems to find out the two-sided interval definition formulas for a and b Weibull parameters. According to them, with the parameterization $a = \ln b$ and $b = \frac{1}{c}$, the following interval estimations are valid:

$$\frac{\hat{c}}{\ell_1\left(\mathrm{n}, 1 - \frac{\alpha}{2}\right)} \le c \le \frac{\hat{c}}{\ell_1\left(\mathrm{n}, \frac{\alpha}{2}\right)} \tag{8}$$

$$\hat{b} \cdot \exp\left(\frac{-\ell_2\left(n, 1 - \frac{\alpha}{2}\right)}{\hat{c}} \right) \le b \le \hat{b} \cdot \exp\left(\frac{-\ell_2\left(n, \frac{\alpha}{2}\right)}{\hat{c}} \right) \tag{9}$$

where the tables for $\ell_i(n, \mathrm{P})$ are presented in Thoman et al. (1969). These tables based on combinations of different confidence levels and numbers of observations describe the distribution of the pivotal function which its underlay parameter Maximum Likelihood Estimators.

6.3. Boundary of Weibull distribution function

As it was mentioned above, queuing systems are the most popular way to simulate and find statistical characteristics of many technical processes including freeway traffic flow. According to the stochastic capacity approach, the capacity of the queuing system which is under consideration has a random meaning in every particular road segment and traffic conditions. In terms of freeway modeling, the Weibull distribution depicts how the capacity dynamically varies within a certain segment. The problem engineers face during simulations is how to limit the produced value not to obtain the capacity too small for the real outer conditions.

From the point of view of classical Kinematics, the density function of the distribution could illustrate the speed of variable changing if the probability $F(x)$ is compared with the position of some body and the meaning of a random value x is compared with a discrete moment. Deducting from these assumptions it is possible to suppose that the second derivate of the distribution function with respect to the same variable is responsible for the acceleration of the variable changing. The investigation of this function could give an answer to the question where the function has minimal and maximal values of the acceleration. Concerning the Weibull distribution and the application to freeway capacity, the determined global maximum doesn't exactly describe the lower threshold, because the probability rate of 1% (instead found 10%) must be included into consideration as being sufficient enough for the onset of congestion on a freeway. It means that the lower threshold is required for the further adjustment. The fist derivative of the density function, as before, is responsible to the speed of its changing. The analysis of this gradient function is associated with finding a new adjusted lower threshold. This curve is not interesting by itself, but the analysis of its changing could be beneficial for detecting the point where the function suffers the minimal change of its growth. This "changing" function has a band and it is supposed that this band is exactly the point where the gradient function has the lowest growth. It is proposed to calculate the band point as an average curvature of the graph of the "changing" function.

There were qualified possible values of Weibull distribution parameters for German freeways. The shape parameter a was varied from its minimal limit 10 to the maximal value 25 in steps of 0.5 when the scale parameter b was changed from 4000 to 7000 in steps of 100. All their combinations underlay the further numerical experiments. It must be mentioned that the same parameters could be applied also for Russian freeways. To improve the accuracy of calculated lower threshold, 10000 realizations of Weibull distributed random value were produced. Based on calculations, the following multiple linear regression model was found. It gives the dependency of realistic values for stochastic capacities based on Weibull distribution parameters:

$$c_{REAL} = -1937 + 108.9 \cdot a + 0.6693 \cdot b \tag{10}$$

Where; c_{REAL}: the realistic value for the stochastic capacity (veh/h); a, b: shape and scale parameters of the Weibull distribution respectively.

Fischer’s F-test applied to the model Eq. 10 allowed rejecting the hypothesis about the simultaneous equality to null for all the estimators; it means that the model is statistically significant and should be taken for the further analysis. Student’s t-statistics for standard errors of all estimators also had a successful result.

7. Conclusion

In spite of the fact that the latest editions of Russian and German National Guidelines still follow the tradition to apply a deterministic understanding of traffic flow characteristics (cf. capacity), the idea to use the stochastic capacity approach is very promising. It was proved that a freeway segment has the capacity exactly fitted with the Weibull distribution. The way to prevent the capacity when modeling smaller than the real value is presented. It is based on the Kinematic understanding of changing the distribution function. Distribution parameters must be bounded by confidence intervals whose construction was based on using pivotal functions.

References

Banks, J.H. 1990. Flow Processes at a Freeway Bottleneck, *Transportation Research Record: Journal of the Transportation Research Board*, 1287: 20-28.

Brilon, W.; Geistefeldt, J. 2010. Überpruefung der Bemessungswerte des HBS fuer Autobahnabschnitte ausserhalb der Knotenpunkte (Revision of the HBS design values for basic freeway segments), *Forschung Strassenbau und Strassenverkehrstechnik*, No. 1033.

Brilon, W.; Geistefeldt, J.; Zurlinden, H. 2007. Implementing the Concept of Reliability for Highway Capacity Analysis. *Transportation Research Record: Journal of the Transportation Research Board*, 2027: 1-8.

Chen, D.; Zhang, J.; Tang, S.; Wang, J. 2004. Freeway traffic stream modeling based on principal curves and its analysis, *IEEE Transactions on Intelligent Transportation Systems*, 5: 246-258.

Codur, M. Y.; Tortum, A. 2015. An Artificial Neural Network Model for Highway Accident Prediction: A Case Study of Erzurum, Turkey, *PROMET-Traffic & Transportation*, 27(3): 217-225.

Dharia, A; Adeli, H 2003. Neural network model for rapid forecasting of freeway link travel time, *Engineering Applications of Artificial Intelligence*, 16(7-8): 607-613.

FGSV 2015. *Handbuch fuer die Bemessung von Strassenverkehrsanlagen – HBS 2015 (German Highway Capacity Manual)*, Forschungsgesellschaft fuer Strassen-und Verkehrswesen, Cologne, Germany.

Geistefeldt, J. 2016. Assessment of Basic Freeway Segments in the German Highway Capacity Manual HBS 2015 and Beyond, *Transportation Research Procedia*, 15: 417-425.Geistefeldt, J.; Brilon, W. 2009. A Comparative Assessment of Stochastic Capacity Estimation Methods. In *Transportation and Traffic Theory 2009: Golden Jubilee, Proceedings of the 18th International Symposium on Transportation and Traffic Theory, Hong Kong*: 583-602.

Hall, F.L.; Agyemang-Duah, K. 1991. Freeway Capacity Drop and the Definition of Capacity, *Transportation Research Record: Journal of the Transportation Research Board*, 1320: 91-98.

Lawless, J.F. 1974. Approximations to confidence intervals for parameters in the extreme–value and Weibull distribution. *Biometrika*, 61(1): 123-129.

Meldrum, D.; Taylor, C. 1994. *Freeway traffic data prediction using artificial neural networks and development of a Fuzzy Logic Ramp Metering Algorithm-Final Technical Report, Washington State Department of Transportation Report No. WA-RD 365.1*, Washington D.C., U.S.A.

Minderhoud, M.M.; Botma, H.; Bovy, P.H.L. 1997. Assessment of Roadway Capacity Estimation Methods, *Transportation Research Record: Journal of the Transportation Research Board*, 1572: 59-67.

Mintrans 1982. *Rukovodstvo po otsenke propusknoy sposobnosti avtomobilnyh dorog (National Guidelines to detect the capacity of motorroads)*, Ministry of Motorroads of the Soviet Union, Moscow, Russia.

Rice, J.; Van Zwet, E. 2004. A Simple and Effective Method for Predicting Travel Times on Freeways, *IEEE Transactions on Intelligent Transportation Systems*, 5(3): 200-207.

Rinne, H. 2009. The Weibull distribution: a handbook, *Chapman & Hall/CRC is an imprint of Taylor & Francis Group, an Informa business*, London, G.B.

Rosavtodor 2012. *Metodicheskie recomendatsii po otsenke propusknoy sposobnosti avtomobilnyh dorog (Russian National Guidelines to detect the capacity of motor roads)*, Ministry of Transport of the Russian Federation, Moscow, Russia.

Thoman, D.R.; Bain, L.J. 1969: Two samples tests in the Weibull distribution, *Technometrics*, 11(4): 805-815.

TRB 2010. *Highway Capacity Manual*, National Research Council, Washington D.C., U.S.A.

Van Aerde, M. 1995. A Single Regime Speed-Flow-Density Relationship for Freeways and Arterials. In *Proceedings of the 74th Transportation Research Board Annual Meeting*.

Ventzel, E.S.; Ovcharov L.A. 1983. *Prikladnye zadachi teorii veroyatnostej* (*Applied Problems of Probability Theory*), Radio i svyaz, Moscow, Russia.

Zurlinden, H. 2003. *Ganzjahresanalyse des Verkehrsflusses auf Strassen (Whole-Year-Analysis of Highway Traffic Flow)*, Dissertation, No. 26, Institute for Transportation and Traffic Engineering, Ruhr-University Bochum, Germany.

SESSION 17: TRANSPORT OPTIMIZATION PROBLEMS

ANALYSIS OF APPROACHES FOR TRAJECTORY COMPARISON

Ekaterina Grakova[1], Jan Martinovič[2], Kateřina Slaninová[3], Tomáš Martinovíč[4], Radek Tomis[5]
[1,2,3,4,5] IT4Innovations, VŠB - Technical University of Ostrava, Ostrava, Czech Republic

Abstract: Measuring similarity between trajectories is undoubtedly one of the most important tasks in trajectory data management since it serves as the foundation of many advanced analyses such as similarity search, clustering, and classification. The paper is focused on distance/metrics to compare two or more trajectories. The authors compared trajectories obtained from several implemented algorithms (Dijkstra's algorithm, A*, Bidirectional Dijkstra, Bidirectional A*) and from external public available routing systems. A collection of the selected routes in the Czech Republic were used for the experiment. The selection of the most suitable metric/distance is very important for the quality enhancement of the routing algorithms; for example, revealing inaccuracies in implemented algorithms or in map data.

Keywords: trajectory similarity measure, GPS trajectories, algorithms, distance/metric.

1. Introduction

The search of paths is an ordinary task for the GPS navigation, and yet most of the navigations easily find a different path, because it depends on the used routing algorithms, used optimizations, and map data. Routing is the process of selecting a suitable route and it takes place in a simplified model of the real transport network – graph. In this graph, there are intersections with nodes of graph and the paths between them are the edges of the graph which are oriented according to the direction. Each vertex has given its GPS coordinates, mainly for the purpose of later plotting of the found path into the map. GPS coordinates consist of two values indicating the position, namely the length and the width. Typically, a GPS trajectory consists of a sequence of points with latitude, longitude, and timestamp information (Bollobás, 1998).
Thanks to this conversion, we can use for the search of paths algorithms that are used for the search of paths in the graphs. The best known algorithm for finding the shortest path in the graph is the Dijkstra's algorithm (Dijkstra, 1959). This algorithm can be used in a graph (either undirected graph, or directed graph). For proper function, the edges must be assessed by their length, which must not be negative, but this case does not occur if the graph represents a road network. Another algorithm that can be used for searching the shortest path is A* algorithm (Hart at al., 1972). It is based on Dijkstra's algorithm and it uses heuristics for searching the path. Its main advantage is that it uses only a fraction of the data for searching the path in comparison with the previously mentioned Dijkstra, so it's much faster. Heuristics consist in the ability of the most accurate estimation of the distance from the current node to the destination node. On the basis of this ability, the path is led directly from the initial node to the end node, which is searched. Therefore, not all the nodes in the graph have to be browsed, but only those lying on the shortest paths. Despite the fact that the shortest path is not found, which is fault of the heuristics, the found path is almost the shortest one.
If we need to find a path only occasionally or if we do not want to buy a GPS for our car, web applications will help us while searching the paths. Among the best known are Google.com, Here.com, Bing.com, Graphhopper.com, Mapquest.com, Tomtom.com. Web applications for routing contain many different functions, e.g. (paid or unpaid highways), which allows us to find a way based on the needs of the user. Most of the web applications search for the shortest and the fastest paths. In this paper, we will concentrate on the shortest paths.
In the experiment, the GPS trajectories from the implemented algorithms and the trajectories from the web applications were compared, and the similarity between two or more trajectories was measured. The similarity of the trajectories can be measured by several metrics. During the last ten years, there were introduced various distance/similarity measures in the literature. Jonkery at al. (1980) suggested Euclidean Distance, Dynamic Time Warping (DTW) was suggested by Soong and Rosengerg (1988), distance based on Longest Common Subsequence (LCSS) presented in (Kearney and Hansen, 1990), Fréchet Distance in (Alt and Gadau, 1995), or Hausdorff Distance in (Huttenlocher at al., 1993). We chose the most common Hausdorff Distance, Fréchet Distance, Dynamic Time Warping for the comparison the trajectories.
The aim of this article is the selection of suitable metrics to compare the results of routing. A suitable metric will enhance the quality of the routing algorithm and reveal inaccuracies in implemented algorithms or in map data.

2. Trajectory Distances

The concepts that were used in the experiment are defined in this section. First of all, let look at the definition of a *trajectory*, which is often used to describe the motion of the moving objects in 2D environment with respect to a given coordinate system:
Definition 1. A trajectory T is a function $F_t : T \to R^2$ which maps a given (temporal) interval $[t_b\,,\ t_e]$ into a one-dimensional subset of R^2. It is represented as a sequence of 3D (2D geography + time) $(x_1\,,\ y_1,\ t_1), (x_2, y_2, t_2), \dots, (x_n, y_n, t_n)$, where $t_b =\ t_1$ and $t_e = t_n$ and $t_1 \le t_2 \le \cdots \le t_n$.

[1] Corresponding author: ekaterina.garakova@vsb.cz

Each point (x_i, y_i, t_i) in the sequence represents the 2D location (x_i, y_i) of the object at the time t_i. For every $t\ (t_i, t_{i+1})$, the location of the object is obtained by a linear interpolation between (x_i, y_i) and (x_{i+1}, y_{i+1}) with the ratio $\frac{(t-t_i)}{(t_{i+1}-t_i)}$, which is, in between two points the object is assumed to move along a straight line-segment and with a constant speed. The 2D projection of T is a polygonal chain with vertices $(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)$ which is called a route of T (Trajcevski at al., 2007). In this paper we chose to use trajectory T in 2D projection.
In the following paragraph we will introduce the most common metric/distance for comparison similarity of two and more trajectories.

2.1. The Fréchet Distance

The Fréchet Distance is amongst the most popular of the similarity measures (Eiter and Minnila, 1944). There was done a lot of studies in which the authors used the Fréchet method to compare the trajectories. (Aung at al. 2013) used metric/distance as the similarity measure in grouping sub-trajectories. Authors of (Buchin at al. 2010) compared similarity geometry of the two trajectories. This method which measures the similarity of the curves is used e.g. when comparing shapes, or when comparing two trajectories or geometries of paths. It is nicknamed "distance of walking dogs" (dogwalk distance). The curves that are subject of comparison can be imagined as trajectories of the dog and his master, who go for a walk and are connected through the leash. Dog and its master can adjust their speeds, they can stop, but must not go back and have to go through the entire route. Fréchet Distance is then the length of the shortest leash with which it is possible to complete such a dogwalk.
The definition of the parameterized continuous curves is presented in Definition 2, and the standard definition for the Fréchet Distance (Alt and Gadau, 1995) follows in Definition 3.

Definition 2. A continuous parameterized curve $A \in R^d$ can be represented by a continuous mapping $f: [a, b] \to R^d$ such that $a, b \in R$ and $a < b$.

Definition 3. A monotone reparameterization α is a continuous non-decreasing function α: $[0,1] \to [0,1]$ such that $\alpha\,(0) = 0$ and $\alpha\,(1) = 1$.

Definition 4. Given two curves, A, B in a metric space, the Fréchet Distance, $d_f\ (A, B)$ is defined as defined as

$$d_f\,(A, B) = inf\ \max_{\alpha,\beta\ t\in[0,1]}\{\mathrm{d}(\mathrm{A}(\alpha(\mathrm{t})), B(\beta(t)))\} \qquad (1)$$

Where; $, \beta$: range over all monotone parameterizations and $d(\cdot,\cdot)$: represents the Euclidean Distance, and *inf* : the infimum.
In the early 1990s, the Fréchet Distance was applied to polygonal curves by Alt and Godau (Alt and Gadau, 1995). With the restriction of polygonal lines, they proved that the Fréchet Distance can be found between two curves *A, B* efficiently with a time complexity of $O\ (mn \log(mn))$ where $m = |A|, n = |B|$.

2.2. The Hausdorff Distance

Another metric/distance, which is used for comparison of two GPS trajectories, is the Hausdorff Distance. The Hausdorff Distance was first defined by Felix Hausdorff in 1914 (Hausdorff, 1914). Since its introduction, the Hausdorff Distance has become one of the most widely used similarity measures across many disciplines. In the paper, the authors (Zhang at al. 2006) compared different similarity measures used for trajectory clustering in outdoor surveillance scenes. Evans at al. (2013) extended the original version of the metric/distance to Network Hausdorff Distance Trajectory Similarity Matrix (NHDTSM). The metric/distance is to quickly calculate the commonly used network Hausdorff Distance between all pairs of the input trajectories. Definition 5 is the basic formulation of Hausdorff Distance.
Definition 5. Let X and Y be two non-empty subsets of a metric space (M, d), where M is the space and *d* the distance measure. We define their Hausdorff Distance $D_H\ (X, Y)$ by

$$D_H(X, Y) = \max\ \{\sup inf_{x\in X,\ y\in Y}\, d(x, y), \sup inf_{y\in Y,\ x\in X}\, d(x, y)\}, \qquad (2)$$

Where; *sup* : represents the supremum, *inf* : the infimum.
In this paper, the metric/distance will be represented as follows. It is the measure of similarity between two arbitrary finite sets *A* and *B*. The classic Hausdorff Distance $H\ (A, B)$ is given by

$$H(A, B) = \max_{a\in A} \min_{b\in B} \|a - b\| \qquad (3)$$

$H(A, B)$ will be small, if each element from *A* is close to an element from *B*. Conversely, $H(A, B)$ will be large if only one element of *A* will be distant to all elements from *B* (Zhang at al., 2006), (Nutanong at al., 2011).

2.3. The Dynamic Time Warning

The method of Dynamic Time Warping (DTW) is an algorithm that takes advantage of the principle of dynamic programming and has been known since the fifties of the last century when it was discovered and began to be popularized through the American mathematician Richard Ernest Bellman (Bellman, 1957), (Psutka, 1996). Subsequently, this method was accepted especially in the area of automatic classification of words and its use in this area has been thoroughly investigated since the seventies. The ability of this method consists in effective measuring the similarity of two time courses.
For two trajectories T_A and T_B, with lengths m and k, an $m \times k$ grid can be created, where each grid point (i, j) represents the distance between points a_i and b_j (Toohey and Duckham, 2015).
Definition 6: If w_l represents a grid point $(i, j)_l$, then a warping path W can be represented as the following sequence of grid points:

$$W = w_1, \dots, w_p \tag{4}$$

The compared time courses processed in the most practical tasks are usually not comparable, and can be shifted against each other or outspread – they are not aligned on the timeline. Because these deviations are not linear, it is not possible to apply the linear comparison (e.g. by measuring the distance of corresponding samples). At linear comparison (for example by measuring the Euclidean distance of corresponding points or vectors), we can two identical time courses erroneously indicate as dissimilar due to uneven alignment on the timeline, though they are only mutually shifted. DTW allows to nonlinearly adapt these time courses by introducing a so-called non-linear, so called collapsing function, which adapts either the tested time course to the referential course or both mutually, in order to achieve the greatest possible conformity.
In the literature, there was introduced a large number of studies for use of DTW to compute the similarity between the trajectories. (Sankoff and Kruskal, 1987) introduced DTW to measure trajectory distance. The authors in (Sankararaman at al., 2013) created framework that uses the advantages of both DTW and sequence alignment based approaches for identifying trajectory similarity, and that it is able to exceed their accuracy. Quantitative analysis on the effectiveness of the trajectory similarity measure was presented in (Wang at al., 2013).

2. 4. Data Description

For the comparison of the trajectories, a set of places among which we searched for the paths was selected. It was necessary to test all of the possible paths. The experiment included the search of short paths, long paths and paths leading from one end to the other end of the Czech Republic. Each path in Table 1 contains the GPS coordinates for the start and the end of the journey. GPS trajectory represents a sequence of points with the latitude and longitude. The resulting GPS trajectories were obtained by means of the implemented algorithms Dijkstra, A*, Bidirectional Dijkstra and Bidirectional A*, which searched for the shortest path.

Table 1
Route for similarity trajectories

Routes	(Start) Latitude / Longitude	(End) Latitude / Longitude
Route 1	50.5732/16.2381	49.1927/17.2903
Route 2	49.1553/15.6161	50.5934/13.5800
Route 3	49.9940/17.5404	49.6767/14.4882
Route 4	49.1726/16.1099	49.4542/15.5905
Route 5	49.9316/12.8500	49.9520/16.1610
Route 6	50.0599/16.4839	49.1345/18.0092
Route 7	50.2096/17.7399	50.5241/16.4257
Route 8	50.6659/14.0911	49.0078/14.8487
Route 9	50.2962/14.2503	49.2496/17.6495
Route 10	50.1057/14.6052	49.9636/13.7695

For the comparison of the results of the tested algorithms, the following web applications for the search of the paths were chosen: Google.com, Here.com, Bing.com, Graphhopper.com, Mapquest.com, Tomtom.com. Each selected application searches for the shortest path. GPS trajectories for similarity comparison were gained by Directions API provided by the web applications. We used Directions API to create a route that included two or more locations and to create routes from major roads. It is possible to create driving or walking routes. Driving routes can include traffic information. Each XML file contained a sequence of points with the latitude and longitude.
Fig. 1 shows a visual trajectory of the routing algorithms and web applications.

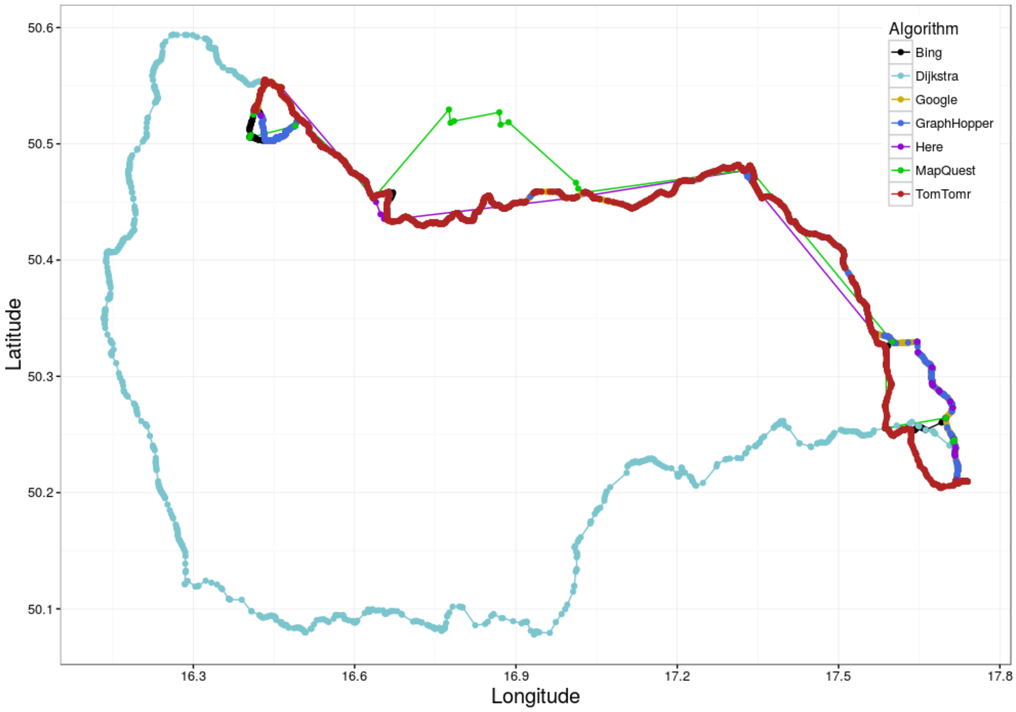


Fig. 1.
Comparison of the trajectories

3. Experiments

To compare the trajectories, we used the Fréchet Distance, Hausdorff Distance and Dynamic Time Warning measure. The implemented similarity measures compare the trajectory of the path of the tested algorithm and the trajectory of the path from the web applications for search of the paths. The points at the start and at the end of the trajectory were identical. Each trajectory in the dataset contained a different set of points. At the beginning, we did the comparison of GPS trajectory from Dijkstra routing algorithm and GPS trajectory of the web applications. In the next step, we made a similarity comparison of a routing algorithm A* trajectory with trajectory from web application. We also compared the bidirectional (Dijkstra and A*) routing algorithms. The results always show the similarity of two trajectories between themselves.

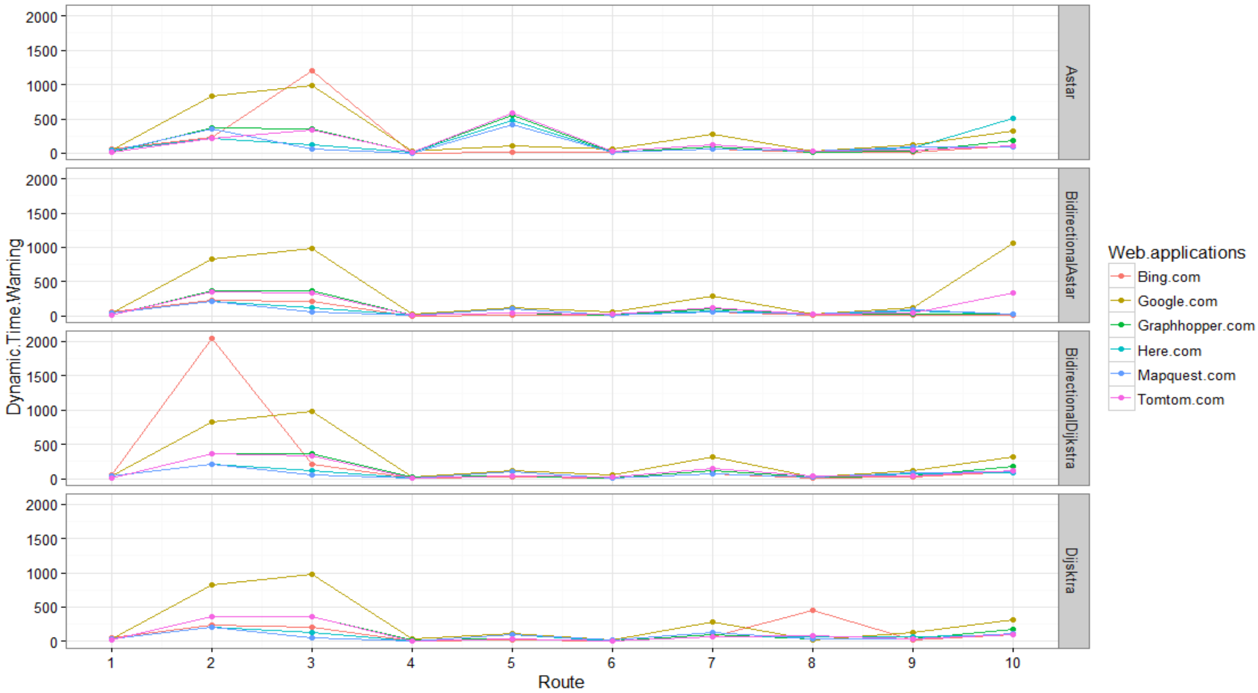


Fig. 2.
The results of a comparison using Dynamic Time Warning

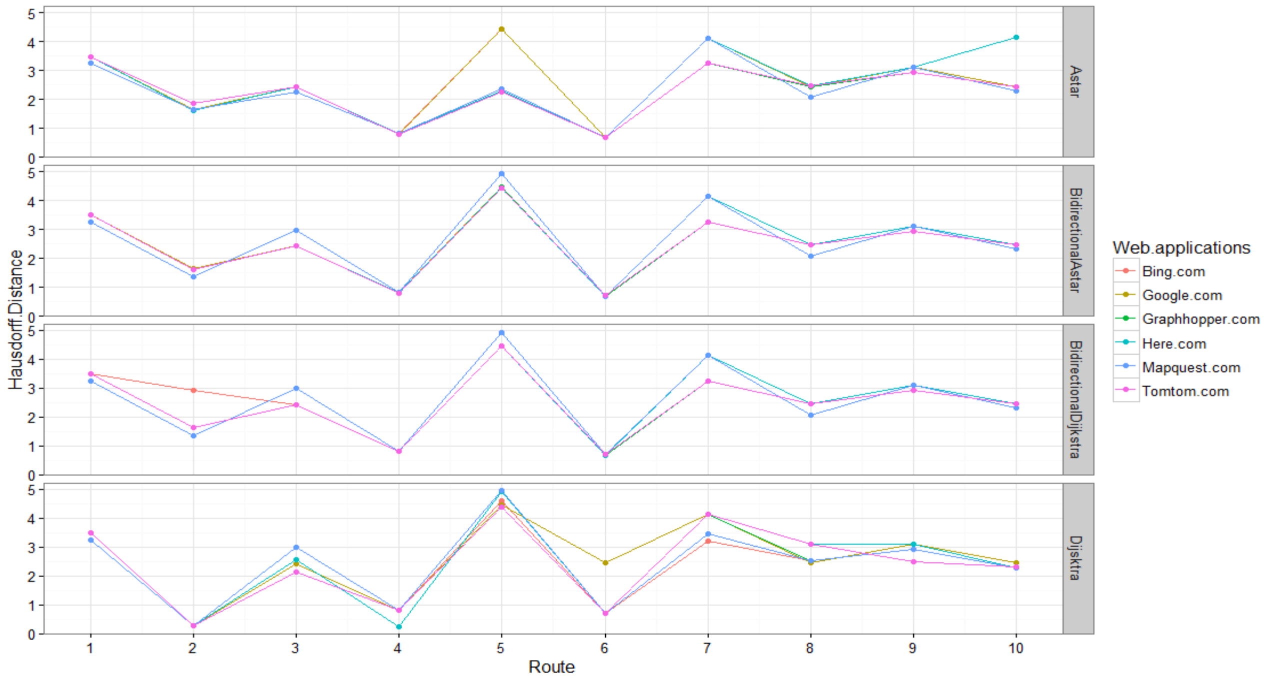


Fig. 3.
The results of a comparison using Hausdorff Distance

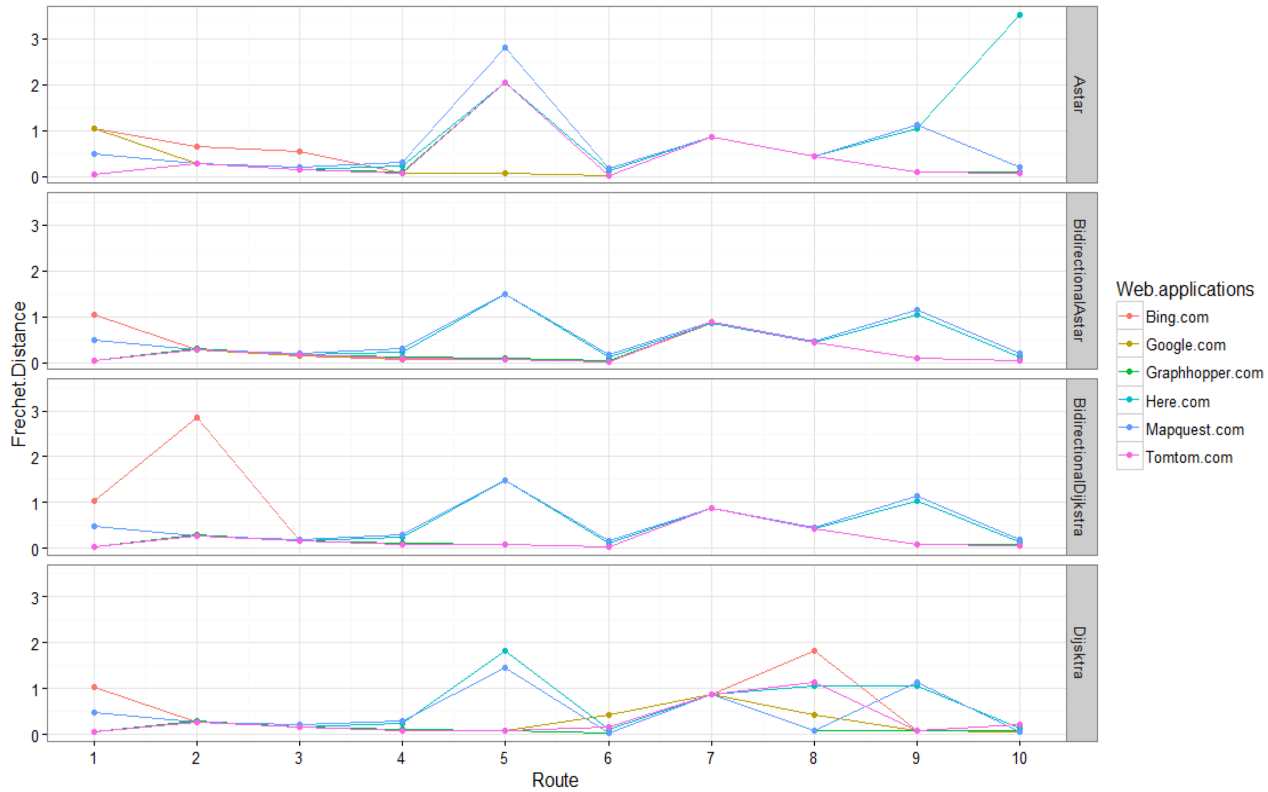


Fig. 4.
The results of a comparison using Fréchet Distance

The values in the pictures are not normalized. The bigger the value of the similarity measure, the smaller similarity between the trajectories is. The Fréchet Distance results are not so big, that they mean; the distance between the two trajectories is minimal, and therefore the trajectories are very similar. The worst comparison similarity results of the two trajectories for Fréchet Distance is route 5. It could have been caused by the quality of the obtained data, which are supplied by the web application or by the calibration of the implemented routing algorithms. Relatively the same similarity results we obtained by Hausdorff Distance. The bigger the Hausdorff Distance, the bigger is the distance between the points in the two trajectories. The high results of the Hausdorff Distance are caused, by the trajectories, which were routed by borders with the Czech Republic by our routing algorithms, which are different from the trajectories from web application. Our routing algorithms searched for the shortest way only within the Czech Republic and web application, for example, had the shortest way going through Poland. As a result the web application algorithms show a different trajectory as opposed to our own routing algorithm. From the results we can see, that the bigger the value of similarity of two trajectories, the smaller similarity is between the trajectories. The worst similarity results we obtained using DTW. The high values of the results could be caused by not defining the distance for points to be considered equivalent. The length of the trajectories between two points can vary by one hundred of meters to one thousand kilometres, and so it can cause big differences in the trajectories.

4. The similarity measures

Table 2 shows us a correlation between the different values of the three used similarity measures. There is a strong correlation between the different similarity values of Fréchet Distance and Dynamic Time Warning. The extreme correlation coefficient (0.7598704) between Fréchet Distance and Dynamic Time Warning was probably caused by the big differences in the length of trajectories. On the other hand, the lowest correlation was between the similarity values, which were executed by Hausdorff Distance and Dynamic Time Warning. Some semi-strong correlation similarity values show Hausdorff Distance and Fréchet Distance.

Table 2
The correlation coefficients between each of the similarity measures

	Fréchet Distance	**Hausdorff Distance**	**Dynamic Time Warning**
Fréchet Distance	−	0.6514869	0.7598704
Hausdorff Distance	0.6514869	-	0.3983476
Dynamic Time Warning	0.7598704	0.3983476	-

Fig. 5 on the left shows that the resulting values have direct dependency. The bigger the values in Table 2 between the Fréchet Distance trajectories we can see of the lower similarity with DTW results (For example route 9). Large discrepancies are always possible when comparing DTW and Fréchet Distances, because they present no bounds on how large the (dis)similarity can be. The high values of DTW could have been caused by its sensitivity and so caused extreme differences in the trajectories. In the left part of the Fig. 5, we can see the results with the weakest coefficient of correlations. It can be caused by Hausdorff Distance not using point matching as opposed to DTW. Fréchet Distance is not really influenced by point matching between the trajectories so much. On the other hand, the value of DTW is influenced, because it requires point matching. Trajectories obtained from the web application are very different in the length of trajectories. For example, trajectory from Here.com contains 30 trajectory points which means that there are large gaps between the points. The trajectory from Dijkstra algorithm has 250 points and therefore, the DTW will show higher values even though the trajectories look similar.

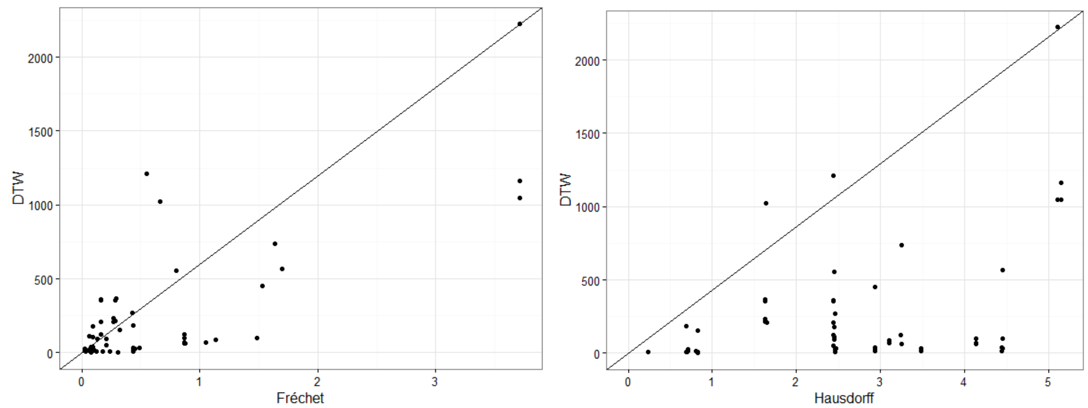


Fig. 5.
Scatter plots comparing the most largely correlated similarity measures, DTW against Fréchet Distance (left) and DTW against Hausdorff Distance ratio (right).

We have found from the obtained results and from the mentioned behaviour typical for DTW, that this method is not suitable for measuring the trajectories. The most suitable metric for the comparison of the trajectories could be Fréchet Distance or Hausdorff Distance. On the one hand, Hausdorff Distance is mathematically simple and is not so much sensitive to the changes in the trajectories. Moreover, Hausdorff Distance allows us to recognize only big differences between the trajectories while ignoring small ones. This behaviour seems the most suitable for the comparison of the two trajectories. Fréchet Distance takes more time to process the information then Hausdorff Distance. On the one hand, the Hausdorff Distance is too ”static”, in the sense that it neither considers any direction nor any dynamics of the motion along the curves. But Fréchet Distance by definition allows us using time to measure the similarity of the two trajectories. For example, one trajectory is faster than the other. It also allows as tracking the speed on the route. In essence, Fréchet Distance considers only the direction (the man and his dog are not allowed to walk back) and the shape of the curves (it chooses the minimum among the leashes for all ways of progression they can make). The best metric/distance for comparison of trajectories from web application and trajectories from our routing algorithms is Fréchet Distance. Fréchet Distance is more accurate and can be adapted to input parameters.

5. Conclusion

In this work, we presented use of similarity measures to compare two or more trajectories in real data. The measures were used to compare GPS trajectories. The data were obtained from well-known web application and from our implemented algorithms. We found differences in the metrics. We determined that the best metric for comparison of trajectories from our routing algorithms and trajectories from web application is Fréchet Distance. Fréchet Distance allow as to compare trajectories in 2D projection, as well as in 3D projection. That way we can detect inaccuracies in implemented route algorithms and so to improve the quality of the routing results.

Acknowledgements

This work was supported by The Ministry of Education, Youth and Sports from the National Programme of Sustainability (NPU II) project 'IT4Innovations excellence in science - LQ1602'.

References

Alt, H.; Gadau, M. 1995. Computing the Fréchet distance between two polygonal curves, *International Journal of Computational Geometry and Applications*, 2(5): 75-91.

Aung, H.H.; Guo, L.; Tan, K. 2013. Mining sub-trajectory cliques to find frequent routes, *Lecture Notes in Computer Science*, 92-109.

Bellman, R.E. 1957. *Dynamic programming*. Priceton, New Jersey, U.S.A.

Buchin, K.; Buchin, M.; Gudmundsson, J. 2010 Constrained free space diagrams: A tool for trajectory analysis, *International Journal of Geographical Information Science*, 24(7): 1101-1125.

Bollobás, B. 1998. *Modern graph theory*, Springer, Berlin, Germany.

Dijkstra, E.W. 1959. A note on two problems in connexion with graphs, *Numerische Mathematik*, 1: 269-271.

Eiter, T.; Mannila, H. 1994. *Computing Discrete Fréchet distance. Technical Report CD-TR 94/64*, Christian Doppler Laboratory for Expert Systems, Wien, Austria.

Hart, P.E.; Nilsson, N.J.; Raphael, B. 1972. *Correction to A Formal Basis for the Heuristic Determination of Minimum Cost Paths*, ACM SIGART, New York, U.S.A.

Hausdorff, F. 1914. *Grundzüge der mengenlehre Hausdorff*, Reiss & Sohn, Leipzig, Germany.

Huttenlocher, D.P.; Klanderman, G.A., Rucklidge, W.J. 1993. Comparing images using Hausdorff distance, *IEEE Transactions on pattern analysis and machine intelligence*, 9(15): 850-863.

Jonkery, R.; De Leve, G.; Van Der Velde; J. Volgenant, A. 1980. Rounding symmetric traveling salesman problems with an asymmetric assignment problem, *Operations Research*, 28(3): 623-627.

Kearney, J.; Hansen, S. 1990. *Stream editing for animation-Technical report*, Department of Computer Science, University of Iowa, U.S.A.

Nutanong, S.; Jacox E.H.; Samet H. 2011. An incremental Hausdorff Distance calculation algorithm, *Journal of Proceedings of the VLDB Endowment*, 8(4): 506-517.

Psutka, J. 1996. *Komunikace s počítačem mluvenou řečí*, Academia, Prague, Czech Republic.

Sankararaman, S.; Agarwal, P.K.; Mølhave, T.; Boedihardjo, A.P. 2013. Computing similarity between a pair of trajectories. arXiv:1303.1585. Available from Internet: <https://pdfs.semanticscholar.or>.

Sankoff, D.; Kruskal, J.B. 1987. *Time warps, string edits, and macromolecules: The Theory and Practice of Sequence Comparison*, University of Chicago Press, Chicago, U.S.A.

Soong, F.; Rosenberg, A. 1988. On the use of instantaneous and transitional spectral information in speaker recognition, *Acoustics, Speech and Signal Processing, IEEE Transactions*, 36(6): 871- 879.

Toohey, K.; Duckham, M. 2015. Trajectory similarity measures, *SIGSPATIAL Special*, 7(1): 2015.

Wang, H.; Su, H.; Zheng, K.; Sadiq, S.; Zhou X. 2013. An effectiveness study on trajectory similarity measures. In *Proceedings of the Twenty-Fourth Australasian Database Conference (ADC 2013).*

Zhang, Z.; Huang, K.; Tan, T. 2006. Comparison of similarity measures for trajectory clustering in outdoor surveillance scenes. In *Proceedings of the 18th International Conference on Pattern Recognition (ICPR'06).*

COMBINING SENSOR TRAFFIC AND SIMULATION DATA TO MEASURE URBAN ROAD NETWORK RELIABILITY

Vincenza Torrisi[1], Matteo Ignaccolo[2], Giuseppe Inturri[3], Nadia Giuffrida[4]
[1,2,3,4] *University of Catania – Department of Civil Engineering and Architecture, Catania, Italy*

Abstract: Travel time is likely to be dissimilar for same spatial trajectories. This underlines the need to think about travel time in terms of frequency, and not just of magnitude. A measure of the dispersion of the travel time distribution is Travel Time Reliability (TTR). Its valuation has been receiving considerable attention in recent years, in freight and especially in passenger transport.
This study addresses this need by proposing a methodology for estimating travel time reliability of an extended traffic network at different aggregation level, by using historical radar detector data and a real-time traffic simulation model, incorporating the analysis and the comparison of various TTR measures. The basic variables used are travel times and traffic flows of each link which belongs to the traffic network. Travel times are estimated through an assignment traffic simulation model and the application of a periodic update with movable horizon called rolling horizon, in order to reproduce the dynamic interaction between the level of congestion and users route choices of a congested road network, that is significant non-linear. The statistical measures used to quantify travel time reliability are Standard Deviation, Travel Time Window, Buffer Index, Planning Time and Buffer Time. The described methodology is applied to the urban area of Catania (Italy). Model is calibrated and tested for different network's sizes at various aggregation levels. The findings of this study should be of interest to transportation planners, traffic engineers, and transit agencies in the form of recommendations for implementing travel time reliability in an extended transport network.

Keywords: Travel Time Reliability (TTR), dynamic traffic model, urban road network, standard deviation, Buffer Index.

1. Introduction

The importance of scheduling in personal and freight activities has grown, so that transport unreliability has an increasingly-marked effect on downstream activities. The expectation from these demand trends is more and more that transport should provide high levels of reliability.
Reliability is unanimously regarded as a desirable transport network attribute. There is less unanimity in defining reliability. Technically, a reliable system is one that performs its required functions under stated conditions for a specified period of time. An alternative definition of reliability draws on the attribute of predictability. In this context, a congested road system where speeds at different times of day and different days of the week are consistent with the forecasting, and hence predictable, would be ranked as highly reliable.
It has been widely recognised that travellers do not only take travel time into account, but also travel time reliability. When travel time is affected by high level of variability, travellers typically allow more time for their trips in order to reduce the possibility of arriving late at their destination. Reducing unreliability means that this extra time allowance could be decreased or avoided completely, presenting a clear user benefit.
For these reasons, the evaluation of travel time reliability (TTR) has been receiving considerable attention in recent years, also in consideration of the current extraordinary availability of real time traffic data from sensors, floating car data and traceable personal mobile devices.
This paper proposes a method for estimating travel time reliability on an extended traffic urban network at different aggregation levels, incorporating the analysis and the comparison of various TTR measures based on the combination of real time collected and simulated traffic data.
The remainder of the paper is divided into six sections. Section 2 provides a description of TTR measures in the general context of transportation and discusses the importance of using different indicators representing reliability for specific purposes. Section 3 describes the methodology identifying the significant model variables. Section 4 describes the case study with the relevant data collected for the model development. Section 5 provides the modelling results. Section 6 is the concluding section where the research findings are summarized and their implications for transport planning are discussed.

2. Measures of reliability in transportation

With the growing recognition that road users are more concerned with travel time variability than delay, recent studies have suggested a greater emphasis on increasing reliability than reducing average travel time for transport planning purposes (Noland and Polak, 2002; Brownstone and Small, 2005; Lyman and Bertini, 2008).
It is important to note that "reliability" will mean different things to each of the parties involved. The network provider perspective and the user-perspective are clearly different. This has led to a clear dichotomy in performance indicators, as reported in Figure 1.

[1] Corresponding author: vtorrisi@dica.unict.it

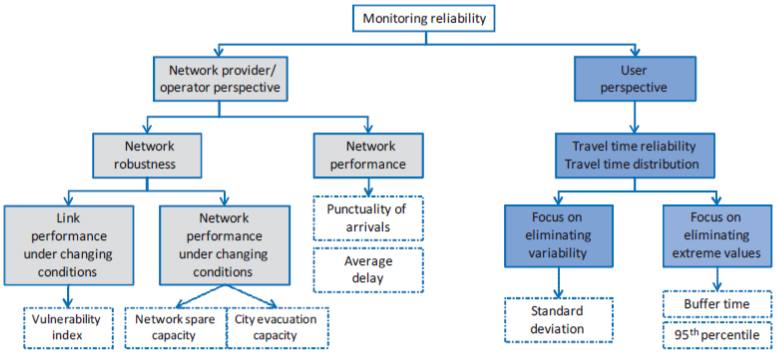


Fig. 1.
Network and uses perspective of reliability
Source: (OECD, 2010)

The user perspective considers specific characteristics of travel times and how he may response to prevailing reliability levels. Research findings suggest that route travel time characteristics are key reliability indicators on road networks (Lo, 2002; Cassir et al., 2001).
The temporal indicators to monitor user perspective of reliability should be used taking into account some considerations regarding the situation for which they can best be used.
Standard deviation is a useful indicator in situations where there is a need to look at the variability in travel times around an average value and it is expected that this variability is not much influenced by extreme delays, the travel time distribution will be not very much skewed (Bates et al. 2001; Lomax et al. 2003).
The 95-percentile value can be used to overcome the eventual problem of not giving much specific attention to possible extreme. This indicator is very appropriate to focus on the range of the travel time distribution and can be very useful to analyse the development of high travel time values.
The Buffer Index can be explained as the extra percentage of travel time due to travel time variability on a trip that a traveller may take into account in order to have a “high” probability of arriving on time. The Buffer Time is the extra time that travellers should add to their average travel time when planning trips relative to the average travel time. The Planning Time Index represents the extra time most travellers should add to a free-flow travel time so as to be fairly confident of arriving at the destination by a certain time. Because these indicators use the 95-percentile value of the travel time distribution, they take into account more explicitly the extreme travel time delays.
This study focuses on Standard Deviation, Travel Time Window, Buffer Index, Planning Time and Buffer Time. These measures are mathematically expressed in the next following section.

3. Methodology

This section presents a methodology for estimating travel times reliability of an extended traffic network at different aggregation levels by using historical radar-detector data and a real-time traffic simulation model, incorporating the analysis and the comparison of various TTR measures.
Travel time is understood as the time elapsed when a traveller displaces between two places in a network. Its duration is related to several factors and it could be dissimilar for similar trips. This underlines the need to think of travel time in terms of frequency, and not just of magnitude. In other words, travel time is defined as a statistical distribution, where the statistics of the variations are thought to exhibit statistical regularity. In this way, travel time reliability can be defined as a measure of the dispersion (or spread) of the travel time distribution.
As stated in section 2, the statistical measures which have been used to quantify TTR are Standard Deviation, Travel Time Window, Buffer Index, Planning Time and Buffer Time.
The Standard Deviation of travel times can be used to describe the extent of travel-time dispersion. It is usually a measure defined in minutes and it can be calculated as shown in Eq. (1):

$$\sigma = \sqrt{\frac{1}{N-1}\sum_1^N (TT_{d,i-j} - M)^2} \qquad (1)$$

where σ is the standard deviation, N is the number of travel time observations in a particular time of day or day of week period, $TT_{d,\,i\text{-}j}$ is a travel time observation on day d during time interval i-j and M denotes the mean travel time.
The Travel Time Window (TTW) is obtained by adding and subtracting the Standard Deviation to the mean trip time (M), as shown in Eq. (2):

$$TTW = \sigma \pm M \qquad (2)$$

The Buffer Index is a buffer time measure, which is normalized to the recurrent travel time and it is calculated with the Eq. (3):

$$B = \frac{(TT_{95} - M)}{M} \qquad (3)$$

where TT_{95} indicates the 95^{th} percentile travel time.
The Planning Time Index represents how much total time a traveller should allow to ensure on-time arrival and it is represented by the Eq. (3):

$$PTI = M \pm M * B \tag{4}$$

The basic variables used are travel times and traffic flows of each link which belongs to the traffic network, estimated through an assignment traffic simulation model (Meschini and Gentile, 2011), periodically updated by real time traffic data through the "rolling horizon" technique, as proposed by Mahmassani (2001), to reproduce the dynamic interaction between the level of congestion and users route choices of a congested road network.
The methodology is tested for different sizes of networks at various aggregation levels. Although many previous studies have focused on corridor- or link-level travel time reliability, this research performs a full range of analysis addressing network level, O-D and path-level, and link-level.
First, N sets of links indexed k = 1, …, N were analysed. It was assumed that estimated travel times and flows were representative of the corresponding link for each time interval during a day d.
The simulation model aggregates traffic data in 15-min intervals to obtain stable values. As a result, each day was divided into 96 time intervals and indexed as i= start of time interval and j= end of time interval. Further, $t_{k,d,i-j}$ is defined as the average travel time at link k on day d during time interval i-j. An array of travel times, symbolised by $T_{d,i-j}$, were constructed for each time interval i-j for all analysed days through the sum of these travel times $t_{k,d,i-j}$, featuring the average total travel time of the considered traffic network, or path or link, as shown in the Eq. (5):

$$\mathrm{T}_{\mathrm{d,i-j}} = \sum_{\mathrm{k=1}}^{\mathrm{N}} \mathrm{t}_{\mathrm{k,d,i-j}} \tag{5}$$

A similar procedure was employed to calculate traffic flows. The total entry flow and the total exit flow of the traffic network can be calculated for the identical set of links by using the same method for estimating $T_{d,i-j}$, as shown in Eq. (6) and Eq. (7):

$$\mathrm{F}_{e_{d,i-j}} = \sum_{\mathrm{k=1}}^{\mathrm{N}} \mathrm{f}_{e_{k,d,i-j}} \tag{6}$$

where: $F_{ed,i-j}$ is the total entry flow of the traffic network, on day d during time interval i-j, in vehicles equivalent units (VEU); $f_{ek,d,i-j}$ is the entry flow at link k on day d during time interval i-j, in vehicles equivalent units (VEU).
Similarly, the total exit flow can be calculated:

$$\mathrm{F}_{u_{d,i-j}} = \sum_{\mathrm{k=1}}^{\mathrm{N}} \mathrm{f}_{u_{k,d,i-j}} \tag{7}$$

where: $F_{ud,i-j}$ is the total exit flow of the traffic network, on day d during time interval i-j, in vehicles equivalent units (VEU); $f_{uk,d,i-j}$ is the exit flow at link k on day d during time interval i-j, in vehicles equivalent units (VEU).
Traffic behaviour changes under different weather conditions and temporal effects (Park et al., 1998; Chung, 2012). Weekdays (from Monday through Friday) and weekends (Saturday and Sunday), have different traffic patterns and characteristics. Therefore, it is essential to analyse them separately. Hence, the traffic data of weekdays and weekends are examined, distinguishing them in working days and non-working day.
This paper also focuses on day-to-day and with-in day travel time variations. The day-to-day variations (variations in travel time when departing at the same time each day) are typically most of interest, as this is the uncertainty that travellers predominantly have to deal with.

4. Case study: data description and model development

Catania is a city of about 300.000 inhabitants, located in the eastern part of Sicily (Southern Italy). The heightened inclination to private mobility has favoured the rise of high car ownership rates and congestion that greatly affects the network reliability.
The described methodology is applied to the urban area of Catania. The study area for this research is broadly represented by the white coloured portion of the territory, whereas the grey portion identifies the neighboring municipalities, which are not included (Figure 2).

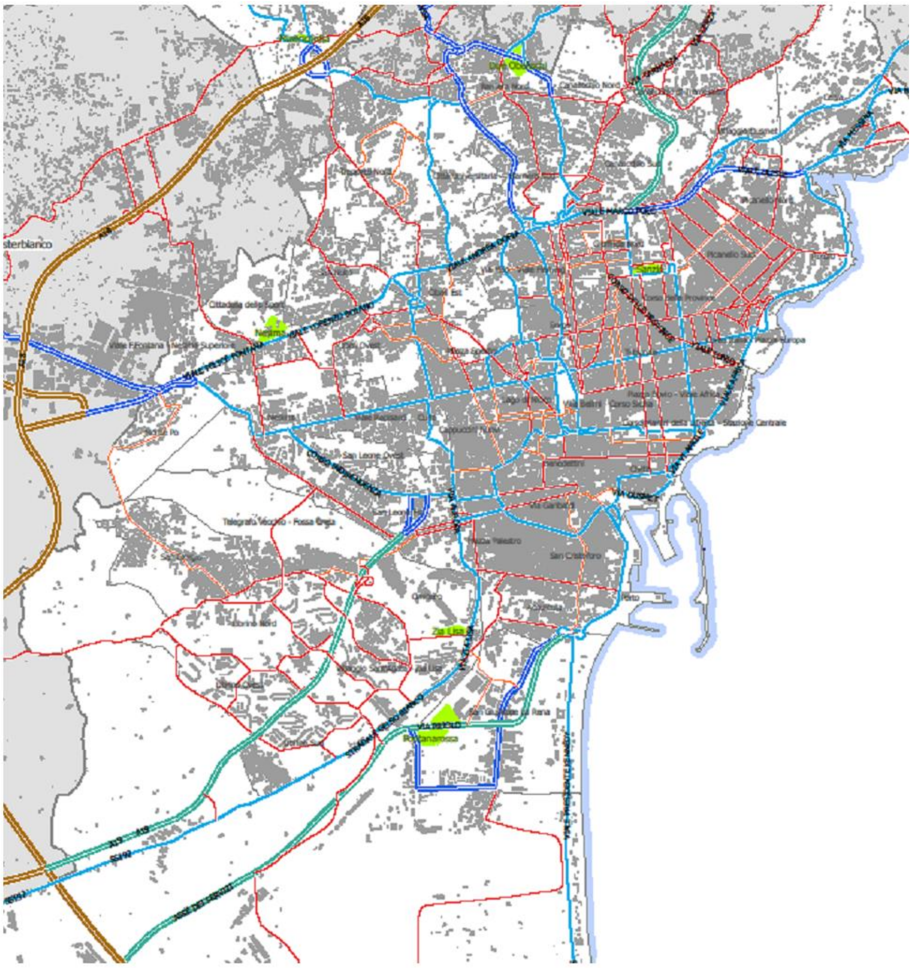


Fig. 2.
Study area and simulated road network

The basic variables used are travel times and traffic flows of each link which belongs to the considered traffic network. They were obtained by the traffic supervisor centre operated by the Department of Civil and Architecture Engineering of Catania's University, where real-time sensor traffic data are combined with simulated traffic data.
This system propagates the spatial and temporal traffic flows measured in less than 1% of the network links and reaching a high level of precision in short term traffic predictions over the whole graph, calculating actual traffic state and predicting its development in the near future. It supplies traffic data including flow, speed, density and queue from simulations integrating available radar detectors' data and Floating Car Data (about 1500 cars), with 15 minutes' time intervals. The amount of data is huge, and so a very precise information can be extracted from them. The 15-min travel times and traffic flows data are simulated for the last year and this year, including weekends and holidays. Because computations are referred to time interval of one hour, simulated traffic data of each 15-min are aggregated and the general form of the proposed model coincides according to these following Eq. (8, 9, 10):

$$\mathrm{T}_{\mathrm{d,i-j}} = \frac{\sum_{\mathrm{k=1}}^{\mathrm{N}} \mathrm{t}_{\mathrm{k,d,i-j}}}{\mathrm{n}} \tag{8}$$

$$\mathrm{F}_{e_{d,i-j}} = \frac{\sum_{\mathrm{k=1}}^{\mathrm{N}} \mathrm{f}_{e_{k,d,i-j}}}{\mathrm{n}} \tag{9}$$

$$\mathrm{F}_{u_{d,i-j}} = \frac{\sum_{\mathrm{k=1}}^{\mathrm{N}} \mathrm{f}_{u_{k,d,i-j}}}{\mathrm{n}} \tag{10}$$

with n = 4 which represents the number of simulation during the time interval of one hour.
These computations refer to traffic data of two weeks, taking into account both working days and non-working day. It was also carry out an analysis on day-to-day travel time variations and on with-in day variations.
As data are distributed according with the Gauss distribution, the general form of Buffer Index of Eq. (3) can be substituted for the proposed model with the Eq. (11):

$$\mathrm{B} = \mathrm{Z} \cdot \frac{\sigma}{\sqrt{\mathrm{n}}} = 1{,}96 \cdot \frac{\sigma}{\sqrt{\mathrm{n}}} \tag{11}$$

where n is the sum of average travel times, σ is the standard deviation for travel times and Z is the reliability coefficient associated to the required level of confidence, equal to 1,96 according to the Z table of the standardized distribution.
Reliability measures have been performed with three aggregation levels: Network level, Path Level and Link Level.
For the first level analysis, the study network is represented by the graph shown in figure 2.

For the second level, three routes with similar lengths connecting the same O/D pair has been selected (figure 3), named in the following “Ognina”, “Passo Gravina”, and “Corso delle Province”. This origin/destination is often used by students, because it connects the University with one of the most important squares for its strategic location, adjacent to many attractions point such as the waterfront, Corso Italia (characterized by numerous shops) and viale O. Pordenone (which allows the connection between the city centre and neighboring municipalities).
The third level concerns the comparison of two links with similar length but different location: Corso Italia link (1.061 meters) in the city centre of the urban area and Viale Marco Polo link (1.262 meters) in the peripheral zone.

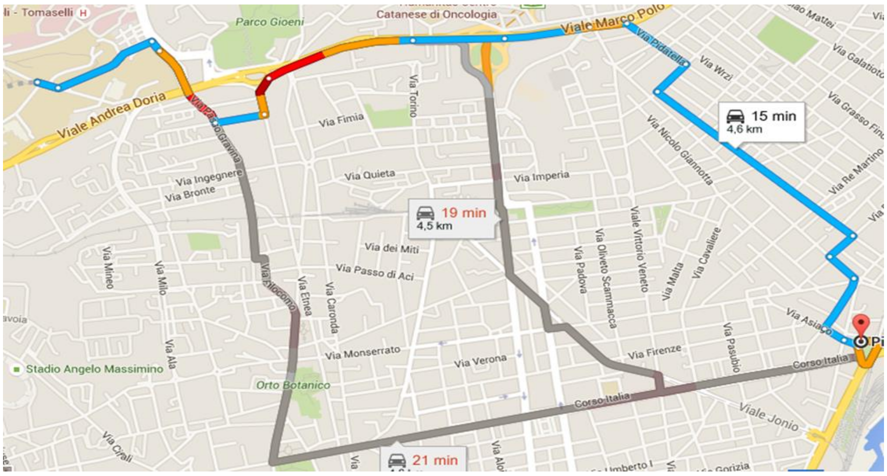


Fig. 3.
Three selected routes: Ognina (right), Passo Gravina (left) and Corso delle Province (middle)

5. Modelling results

In this section the value of TTR at different network aggregation levels are examined to evaluate the significance and utility of different measures.
The analysis at network level was performed by using average travel times and traffic flows calculated starting from the characteristics of each individual link that belongs to the considered transport network. Thus, it is possible to globally describe the characteristics of the network. Table 1 summarizes the results related to Buffer Index, Planning Time and Buffer Time and the difference between average travel time and planning time is represented in figure 4. Figure 5 shows the relationship between average travel times and traffic flows: with increasing traffic flows there is also a proportional increase in travel times. This happens particularly at peak hours and on weekdays due to commuting phenomenon.
Path level analysis is also focused on the same traffic variables. For an even more detailed study, it was performed a day-to-day variations and with-in day variations analysis of travel times and traffic flows, determining the values of average travel time, standard deviation, buffer index, planning time and buffer time for each selected path, as shown in Tables 2 and 3. The same methodology was applied to the third aggregation level and results are shown in Table 4.

Table 1
Network level analysis: Buffer index, planning time and buffer time

	Network			
Day	**Average travel time [h]**	**Buffer index**	**Planning time [h]**	**Buffer time [min]**
16/06/2016	28.445	1.50%	28.872	25.601
18/06/2016	28.433	1.34%	28.814	22.860
19/06/2016	28.119	0.04%	28.130	0.675
20/06/2016	28.442	1.55%	28.883	26.451
23/06/2016	28.462	1.70%	28.946	29.031
25/06/2016	28.430	1.31%	28.802	22.346
26/06/2016	28.119	0.05%	28.133	0.844
27/06/2016	28.465	1.65%	28.935	28.181

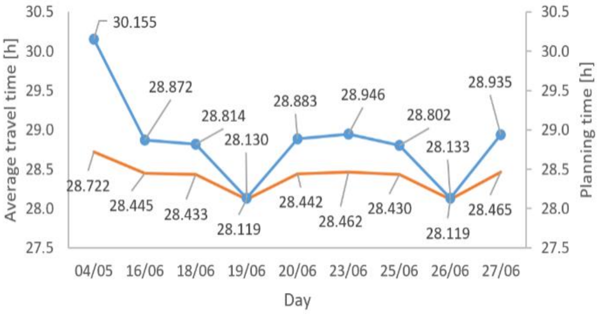


Fig. 4.
Network level analysis: with-in day variations of planning time

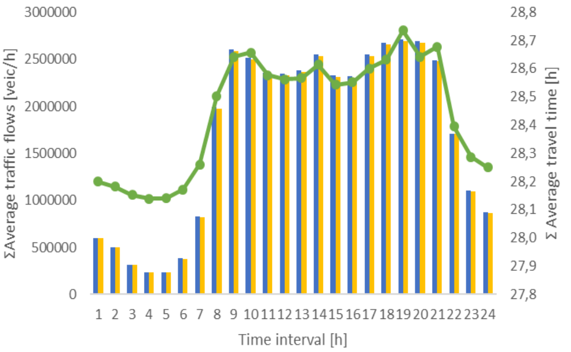


Fig. 5.
Network level analysis: with-in day variations of average travel times and traffic flows
Source: (Campagna, 2016)

Table 2
Path level analysis: Average travel time and standard deviation

Day	Ognina path		Passo Gravina path		Corso delle Province path	
	Average travel time [min]	Standard deviation [sec]	Average travel time [min]	Standard deviation [sec]	Average travel time [min]	Standard deviation [sec]
16/06/16	9.073	9.95	11.645	13.56	9.200	10.48
18/06/16	9.025	6.84	11.601	8.80	9.182	8.24
19/06/16	8.805	0.44	11.312	0.53	8.914	0.57
20/06/16	9.096	14.77	11.607	11.11	9.220	15.24
23/06/16	9.105	13.73	11.61	11.12	9.233	14.36
25/06/16	9.023	7.02	11.588	9.13	9.181	8.46
26/06/16	8.805	0.42	11.312	0.60	8.912	0.56
27/06/16	9.084	10.52	11.614	11.39	9.280	16.74

Table 3
Path level analysis: Buffer index, planning time and buffer time

Day	Ognina path			Passo Gravina path			Corso delle Province path		
	Buffer index	Planning time [min]	Buffer time [sec]	Buffer index	Planning time [min]	Buffer time [sec]	Buffer index	Planning time [min]	Buffer time [sec]
16/06/16	2.20%	9.273	11.976	1.35%	11.802	9.432	2.30%	9.412	12.696
18/06/16	1.52%	9.162	8.230	0.88%	11.703	6.125	1.81%	9.348	9.972
19/06/16	0.07%	8.811	0.369	0.04%	11.317	0.271	0.09%	8.922	0.481
20/06/16	3.26%	9.393	17.791	1.10%	11.735	7.661	3.35%	9.529	18.532
23/06/16	3.03%	9.381	16.552	1.11%	11.739	7.732	3.15%	9.524	17.450
25/06/16	1.56%	9.164	8.445	0.91%	11.693	6.327	1.86%	9.352	10.246
26/06/16	0.06%	8.810	0.316	0.04%	11.317	0.271	0.08%	8.919	0.428
27/06/16	2.33%	9.296	12.699	1.14%	11.746	7.944	3.67%	9.621	20.435

Table 4
Link level analysis: Buffer index, planning time and buffer time

Day	Corso Italia link					Viale Marco Polo link				
	Average travel time [min]	Standard deviation [sec]	Buffer index	Planning time [min]	Buffer time [sec]	Average travel time [min]	Standard deviation [sec]	Buffer index	Planning time [min]	Buffer time [sec]
16/06/16	2.785	6.07	1.24%	2.820	2.072	3.112	2.99	1.13%	3.147	2.110
18/06/16	2.758	2.83	0.58%	2.774	0.959	3.098	2.13	0.81%	3.123	1.506
19/06/16	2.670	0.09	0.01%	2.670	0.016	3.030	0.19	0.05%	3.032	0.091
20/06/16	2.771	3.73	0.76%	2.792	1.263	3.112	3.12	1.18%	3.149	2.203
23/06/16	2.772	3.73	0.76%	2.793	1.264	3.115	3.16	1.20%	3.152	2.243
25/06/16	2.758	2.87	0.59%	2.774	0.976	3.100	2.18	0.83%	3.126	1.544
26/06/16	2.670	0.10	0.01%	2.670	0.016	3.030	0.18	0.05%	3.032	0.091
27/06/16	2.773	3.79	0.78%	2.795	1.297	3.125	3.63	1.37%	3.168	2.569

As shown in these tables, all standard deviations of parameter distributions were significantly different from zero. When travel time on a link varies widely, Standard Deviation is high and reliability is low. On the other hand, when all trips take more or less the same time, Standard Deviation is low and reliability is high.
The analysis of Buffer Index indicates that as the buffer time metric decreases, TTR increases. The elaborations deriving from the comparison of different paths, show in some cases that routes with higher values of average travel time presents best results as regards travel time reliability.
These results indicate that it is possible to test the direct link between traffic congestion and TTR. In fact, the higher divergence is during weekdays, when the phenomenon of commuters is greater. However, a congested network does not have to be unreliable. Unreliability refers to unanticipated delays, and therefore a congested network is not necessarily unreliable because journey time along a congested road can be fairly predictable. That said, it is also recognised that remedial actions directed at congestion can improve reliability and, similarly, actions that improve reliability can reduce congestion. This assessment is synthesised in the next section into recommendations for implementing travel time reliability in extended transport network.

6. Conclusions

In this paper, reliability is defined as the ability of the transport system to provide the expected level of service quality, upon which users have organised their activities. The key word is "expected". According to this definition, reliability can be improved either by supplying a higher level of reliability, or by changing expectations of the level of reliability.
As stated in the introduction, the evaluation of travel time reliability has been receiving considerable attention in recent years, and a robust and consistent assessment of network performances should be developed in order to ensure good level of reliability.
In this way, the paper proposes a methodology for estimating travel time reliability of an extended traffic network, incorporating the analysis and the comparison of various TTR measures. Although many previous studies have focused on corridor- or link-level travel time reliability, this research performs a full range of analysis addressing to different aggregation level: network level, path-level, and link-level.
In this regard, an effective and efficient procedure for collecting and gathering traffic data is essential to perform an accurate assessment and analysis of transport network and its components. However, the collection of comprehensive and reliable traffic data is challenging in many ways. Data collection is often inadequate, incomplete, imprecise and expensive.
This study overcome this issue taking advantage of Intelligent Transportation Systems (ITS) technologies, in particular by using the traffic data obtained through an assignment traffic simulation model.
The basic variables used are travel times and traffic flows of each link which belongs to the network and they were used for calculating and comparing different TTR measures: Standard Deviation, Travel Time Window, Buffer Index, Planning Time and Buffer Time.
Results show that these temporal indicators to monitor user perspective of reliability should be used taking into account some considerations regarding the situation for which they can best be used. Their use is important for informing decisions on achieving more optimal levels of reliability on surface transport networks, and for the selection of best action strategies. For this purpose, there are many techniques and instruments available that can be used to improve the reliability of the transport network: physical expansion of capacity, better management of capacity, pricing mechanisms to deliver a market for reliability and information systems intended to mitigate the adverse consequences of unreliability, rather than to reduce the incidence of the unreliability.
Focusing on the last one, information systems can reduce the consequences of network unreliability. Network demand can be deflected away from the site of congestion or traffic incidents. Information can be provided to users to mitigate the effects of poor reliability; it can also reduce stress associated with unreliability, and enable the problems associated with delays to schedules to be managed. Different tools exist for delivering this information, including variable message signs, car navigators, the internet, and text messages on mobile phones.
In conclusion, by conducing similar analysis in other regions, transport planners and agencies can determine how local factors affect travel time reliability and whether they can improve reliability by imposing travel-time penalties or other mechanisms on trips to and from specific locations based on real-time traffic data.
Further research needs to be conducted to investigate the temporal and spatial stability of the proposed models as well as to validate the results of this study. The presence of only some traffic parameters in the models might suggest that other variables may improve the model specifications, thus additional variables might be examined in future studies.

References

Bates, J.; Polak, J.; Jones, P.; Cook, A. 2001. The valuation of reliability for personal travel, *Transportation Research Part E (Logistics and Transportation Review)*, 37(2/3): 191-229.
Brownstone, D.; Small, K.A. 2005. Valuing time and reliability: assessing the evidence from road pricing demonstrations, *Transportation Research Part A: Policy and Practice*, 39(4): 279-293.
Campagna, A. 2016. Misure di affidabilità nelle reti di trasporto stradali: il caso di Catania. Master thesis. University of Catania, Italy.

Cassir, C.; Yang, H.; Ka Kan, L.; Tang, W.; Bell, M. 2001. Travel time versus capacity reliability of a road network, Reliability of transport networks, *Research Studies Press Ltd.*, United Kingdom.

Chung, Y. 2012. Assessment of non-recurrent congestion caused by precipitation using archived weather and traffic flow data, *Transp. Policy*, 19(1): 167-173.

Lo, H. 2002. Trip travel time reliability in degradable transport networks. In *Proceedings of the 15th International Symposium on Transportation and Traffic Theory (ISTTT). Adelaide, South Australia.*

Lomax, T.; Schrank, D.; Turner, S.; Margiotta, R. 2003. *Selecting travel reliability measures*. Texas Transportation Institute, Cambridge systematics, Inc.

Lyman, K.; Bertini, R.L. 2008. Using travel time reliability measures to improve regional transportation planning and operations, *Transportation Research Record: Journal of the Transportation Research Board*, 2046: 1-10.

Mahmassani, H.S. 2001. Dynamic network traffic assignment and simulation methodology for advanced system management applications, *Networks and Spatial Economics*, 1(3-4): 267-292

Meschini, L.; Gentile, G. 2011. Real-time traffic monitoring and forecast through OPTIMA – Optimal Path Travel Information for Mobility Action. *2nd International Conference on Models and Technologies for Intelligent Transportation Systems.* Leuven, Belgium, 22-24 June 2011.

Noland, R.B.; Polak, J.W. 2002. Travel time variability: a review of theoretical and empirical issues, *Transport Reviews*, 22(1): 39-54.

Organization for Economic Co-Operation and Development OECD/ITF, 2010. *Improving Reliability on Surface Transport Networks*. OECD, Paris.

Park, B.; Messer, C.; Urbanik Ii, T. 1998. Short-term freeway traffic volume forecasting using radial basis function neural network, *Transport. Res. Record: J. Transport. Res. Board*, 1651: 39-47.

THE VITALITY OF TRAFFIC DIRECTIONS IN ROAD NETWORKS WITH RECURRENT CONGESTION AND ITS EFFECT ON ROAD TRAFFIC DESIGN

András Szele[1], Lajos Kisgyörgy[2]
[1] Institute for Transport Sciences, Hungary
[2] Budapest University of Technology and Economics, Hungary

Abstract: In a case study about congestion in Budapest it is presented that in case of excessive congestion in the main direction of traffic flow, traffic from minor directions can still very easily access the overcrowded main direction. This phenomenon was named the vitality of the minor directions. Our study focuses on the vitality of these traffic directions, its changes during congestion, and its applicability in traffic design. The vitality of traffic directions was defined. The aggregated vitality of the minor directions and the speed of the main direction were found to be closely linked. The concept of vitality quantifies the change of traffic routing, including its network effects under congested and normal traffic conditions, on road networks with recurrent congestions. The methodology for designing a congestion-related road network provides a design method that can play a key role in effective urban traffic control strategies at both a strategic and a tactical level.

Keywords: congestion-related approach, road design in road network, recurrent congestion, congested intersection, traffic direction vitality.

1. Introduction

Congestions in modern cities have become a customary and accepted attribute of traffic operation. On the road networks of urban areas, congestions are usually caused by the lack of capacity of one, or sometimes more, cross sections. The lack of capacity takes a variety of forms: long queues, unacceptably low speeds, unreliable travel times and delays, which all result in a transport system with higher costs. The main roads in urban areas are so heavily and recurrently congested for longer periods that forecasted traffic volumes have in recent decades regularly exceeded the design capacity of the roads. Therefore, designing congested road transport networks is the biggest challenge in contemporary transport planning.

According to the OECD-ECMT Summary Document (2007), congestion in cities is generally the result of prosperous urban economic increase. The most important task nowadays is not to eliminate congestion but to avoid excessive congestion, principally when worthwhile solutions are applicable. The congestion can be considered excessive when the marginal costs of congestion top the marginal costs of reducing congestion. Much remains to be done to solve the problem caused by the oversaturated roads, but there is no ideal solution. The traditional strategic and design solutions either release existing capacities or build new road capacities. Both of them represent a temporary solution: the traffic of congested road networks will need to be managed in the near future. Goodwin (2004) pointed out that there is no known worthwhile solution to solve the congestion problem and only road charges and its complementary actions work in practice.

Recurrent congestion is caused by regularly or periodically acting factors on the road network and shows a high degree of variability in some of its factors. When near full capacity, the vulnerability of traffic to rapid disruption is very important in the formation of traffic jams. Congestion has an impact on both average travel speed and travel time reliability, with reliability being more important for road users (OECD-ECMT, 2007).

Literature contains a wide range of studies on road congestion. The findings are generally either too sophisticated for traffic design, too complicated, or are not compatible with the design system. New methodologies for the traffic design of road networks with recurrent congestion is not within the focus of attention of designers and was not included in the standard design procedure until the 2000s (Garber and Hoel, 2009), even though the necessary calculation procedures had been available since the 1950s. These procedures have stood the test of time well. However, it is worth underlining that these calculations generally will not be implemented in the design process (Hobbs, 1979) and the methods only appeared in comprehensive design books around the end of the 2000s (Bell at al., 2006). The most cited calculation method is the shock wave theory (Lighthill and Whitham, 1955), which can be easily applied by traffic designers.

During the design process of road networks for densely built-up areas, designers generally do not have enough space or funds for a good solution to improve traffic operation. Congested traffic cannot be efficiently managed by the traditional tools of traffic engineering: they require a new, congestion-related approach. This congestion-related approach accepts congestions and rather tries to influence, regulate and manage the existing demands. The use of the tools of the congestion-related approach requires a thorough analysis of the reasons for and effects of road networks with recurrent congestions. New approaches are needed to improve the new design tools for this well-known traffic phenomenon. The signs of a promising new approach were described by Vörös and Szele (2005) in a case study about congestion in Budapest. As Vörös and Szele pointed out, in excessive congestions the traffic of the minor directions could very easily ingress in the congesting main direction. This phenomenon was named the vitality of the minor directions.

[2] Corresponding author: kisgyorgy@uvt.bme.hu

Literature contains no studies on the chosen topic, so this research aims to fill a void. The study focuses on the vitality of the traffic directions, its change during congestions, and especially on its applicability in traffic design. Using the vitality of the traffic directions to study road networks afflicted with recurrent congestion is a new approach that quantifies the network effects of the congestions. The preparation of a congestion-related road network design methodology provides to elaborate a design method that actually works in practice.

2. Methodology

The vitality of a traffic direction was interpreted in the following framework model. The users of a road network with recurrent congestions generally use a certain road section on an everyday basis, with most drivers being familiar with the usual traffic jams and the rat-runs. Motorists formulate their own strategies to cope with the problem. The most important coping method is routing, by which drivers decide which route they prefer for their trip. The basic decision is choosing between the congested main direction or one of the rat-runs. Unfortunately, drivers located at the decision points are not always in possession of enough information to make a good decision (for instance, the congested road section is not visible), as a result of which many motorists plan their journeys by using the rat-runs in the usually congested periods, without taking into account the rate of congestion at all.

In the period before congestion, the traffic of the main direction remains on the main road and doesn't look for rat-runs. The traffic from the minor directions seeks out the fastest (which is also the shortest) path to merge with the main direction. During this time, drivers choose the main direction. When the congestion time starts, often independently of the actual traffic situation, an increasing number of motorists choose the rat-runs. During the congestion, the drivers avoid the main direction and search for the fastest route that leads to the congestion-causing cross section, to thereby merge into the overcrowded main direction as closely as possible to the bottleneck.

The reason for the congestion in the main direction is the lack of capacity in the congestion-causing cross section. The small available capacity of this cross section should be used by the main direction, but the vehicles entering at nearby intersections overuse this capacity when they overtake the vehicles in the queue formed in the main direction. That is the reason why the congestion spreads and becomes excessive. The consequences of these processes are the increased amount of traffic on the rat-runs and more merging traffic near the congestion-causing cross section, which further deteriorates the flow of the main direction. The recurrent congestion of the main directions is partly caused by the drivers' expectations of traffic and their decision to use rat-runs. Consequently, the formation and spreading of the congestion is a self-generating process.

The traffic demand behind this process is the well-known principle that drivers take the routes with lowest costs and that are generally the fastest as well. In the case of the congested road network, the lowest cost route for drivers queuing in the main direction is to choose the rat-run to avoid the congestion. However, for drivers arriving from the minor directions, the lowest cost route is to avoid the congested road sections and enter the network as closely as possible to the congestion-causing cross section. The result of both coping strategies is the development of traffic on the rat-runs, which seeks out the merger point closest to the congestion-causing cross section. This process generates a significant traffic demand near the bottleneck.

On a road network with recurrent congestion, all traffic directions have a certain capability, which is determined by its location, design, and regulations. These capability shows the extent to which certain traffic directions allow traffic to reach the congestion-causing cross section. This capability is referred to as the vitality of the direction. To quantify vitality, it is proposed to use the quotient of the traffic volume in the examined direction and the egressing traffic volume of the congestion-causing cross section (Fig. 1.). The unit of measurement is the percentage value (%). The capacity of the congestion-causing cross section is finite. As a result, as the vitality of one direction increases, the vitality of another direction decreases. If the vitality of the minor directions increase, the vitality of the main direction will decrease. The aggregated vitality of all minor direction is the reciprocal of the vitality of the main direction. It is assumed that the concept of vitality will play an important role in the description, understanding, and design of road networks with recurrent congestion.

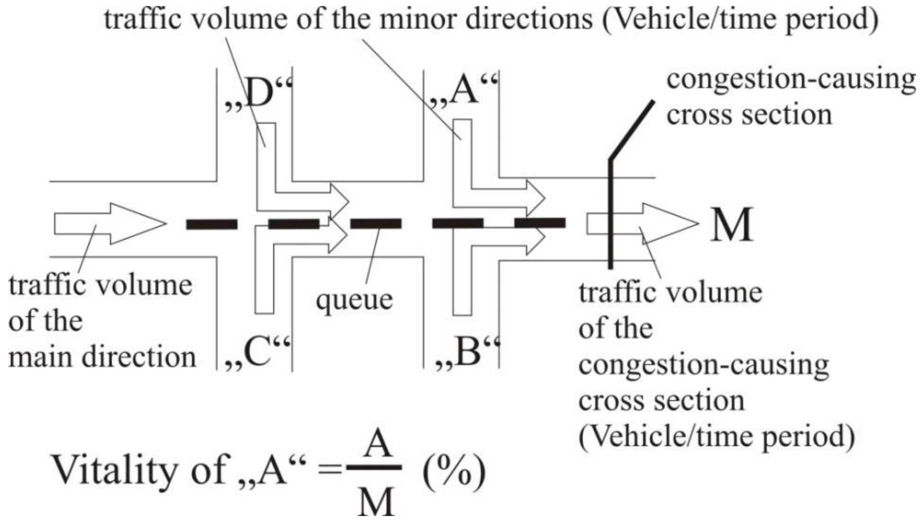


Fig. 1.
The vitality of the traffic directions on a road network with recurrent congestion

The study has to find an answer to the question: Is there a relationship between the vitality of the directions and the degree of congestion? The study used the aggregated vitality of the minor roads, which is equal to the sum of the vitality of all the minor directions. Traffic observation, traffic measuring, and simulation were used to determine the principal components behind vitality. The examinations were implemented on road networks with traffic lights where there was no way to avoid the congestion-causing cross section. It was important that there should be no other congestion-causing cross section or congested crossing roads on the chosen network, so traffic directions could clearly be segregated. For the proper results, the traffic had to make it possible to select both routes and the merging-point to the main direction freely. Such a road network was found in a suburb of Budapest.

3. Data collection

Data was collected by recording videos in Budapest and in its suburbs. This was followed by the determination of changes in the traffic volumes of the main direction and the merging minor directions, as well as of travel times in the main direction. The data collections were conducted in the morning peak hours. The temporal change of traffic volumes and vitality was calculated on the basis of the data. The minor roads with excessive vitality and the most important traffic factors are shown in the figures. Two locations were chosen to collect data for the research.
The first location, Egér Road in Budapest (Fig. 2.), links the southwestern suburbs and the south of Budapest. The involved four-lane road section is 3.5 km long, with traffic regulated by 6 signalized intersections. The collected data was used to perform traffic simulations, the outcomes of which were used for the analysis.

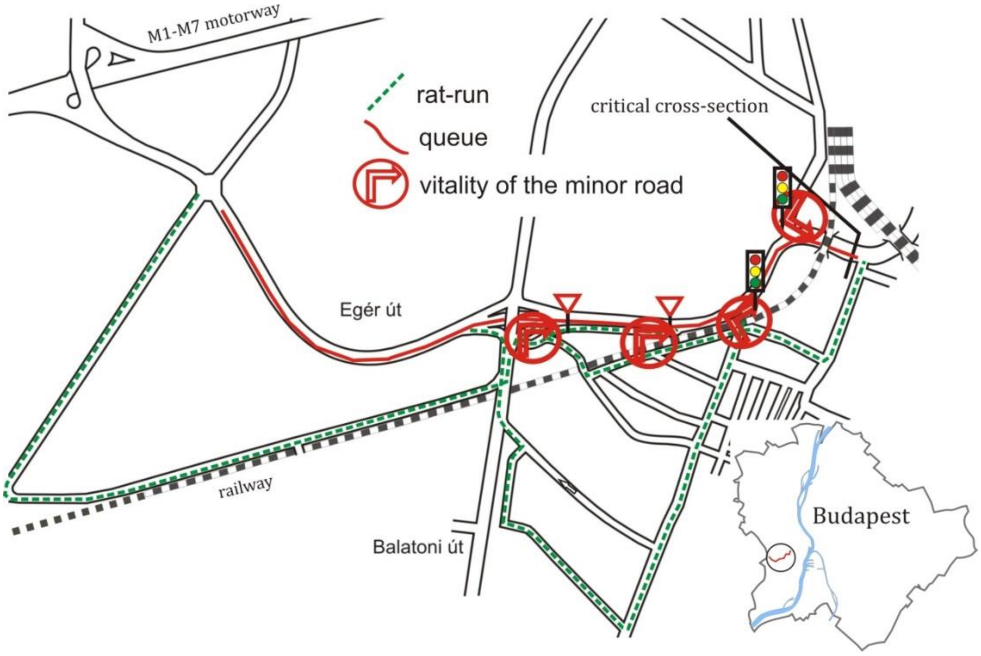


Fig. 2.
Minor directions with excessive vitality on Egér Road, Budapest

The second location, Balatoni Road in Diósd (Fig. 3.), plays an important role in commuter traffic to Budapest and the M0 ring around Budapest. The involved two-lane road section is 1.2 km long and contains two roundabouts and 6 additional minor roads regulated by “Give Way” signs at their respective junctions. The outcomes of the collected data were used directly for the purposes of the analysis.

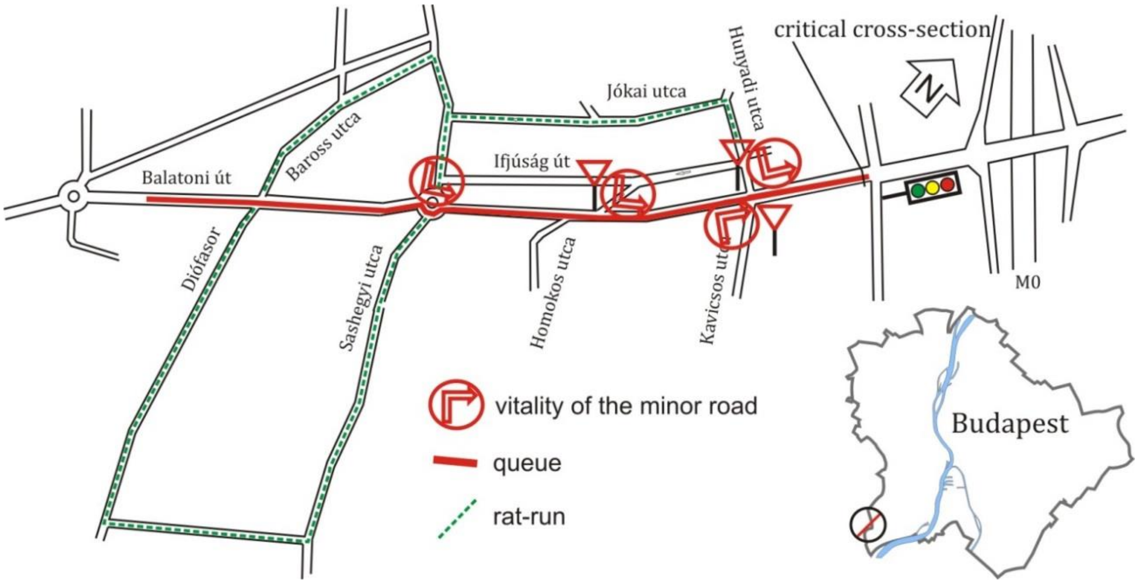


Fig. 3.
Minor directions with excessive vitality on Balatoni Road, Diósd

4. Is there a relationship between the vitality of the directions and the degree of congestion?

To answer this question, a traffic simulation was based on the traffic measured on Egér Road during congested conditions. Five minute units of the simulation traffic volume results were added together to specify the vitality of all directions. The vitality of all minor directions was aggregated to compare the vitality of the main direction. The congestion degree has been taken into account as the 5-minute-average travel speed of the congested main direction. A faster travel speed means a lower degree of congestion. The aggregated vitality of all minor direction (Fig. 4.) before the formation of the congestion was 36%, which increased to 64.5% as the congestion worsened. Though the variation of the vitality showed a clear increasing tendency, the increase was volatile: there were significant differences even in the 5-minute-average values. During the congestion, the speed of the main direction was almost uniformly descending. The aggregated vitality of the minor directions and the travel speed of the main direction change together.

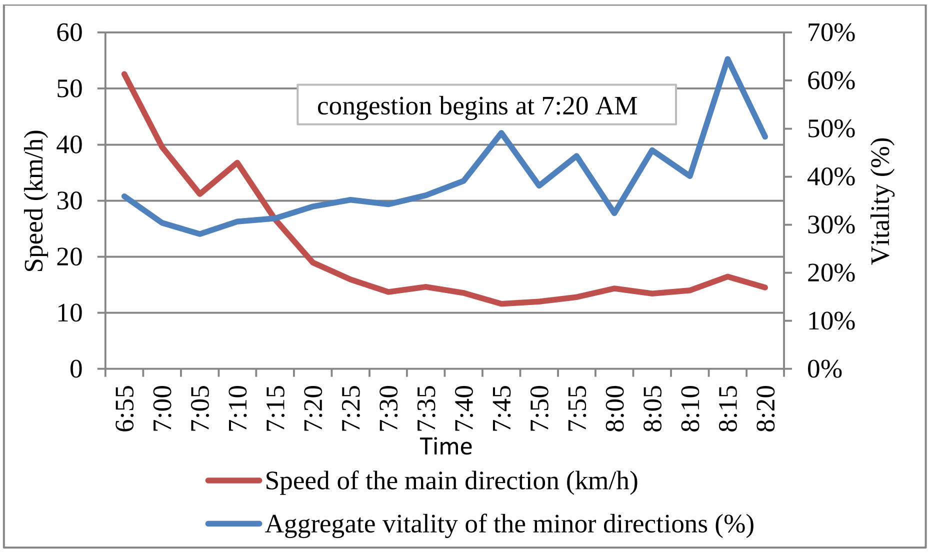


Fig. 4.
The change of the aggregated vitality of the minor directions and the speed of the main direction during the congestion time on Egér Road, Budapest

In the case of Balatoni Road in Diósd (Fig. 5.), the traffic volumes of all directions were counted and aggregated to a 5-minute-average to specify the vitality of all the directions. The travel speed of the main direction was measured and averaged to a 5-minute-average as well. In this case, the aggregated vitality of all minor directions showed a non-uniform ascending tendency starting from 32.3% (before the formation of the congestion) to a value of 67.7% (at the lowest speed in the main direction). The non-uniformity of the increase can be explained by the temporary decrease in the vitality of the minor roads as the queue accelerates at the green signal. During the congestion, the speed of the main direction was almost uniformly descending. In this case, the aggregated vitality of the minor directions and the travel speed of the main direction also changes together; however, the relationship between these factors is not clear.

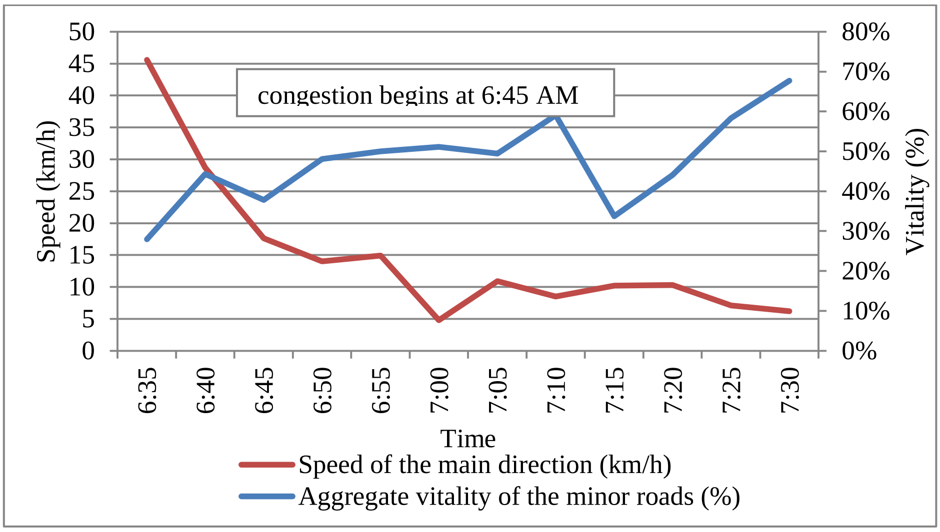


Fig. 5.
The change of the aggregated vitality of the minor directions and the speed of the main direction during the congestion on Balatoni Road, Diósd

To understand the relationship between the speed of the main direction and the aggregated vitality of the minor roads during the congestion, charts were created based on the results of the measurements that examined congested road networks. As shown by Figure 6, Egér Road experienced only small changes in the aggregated vitality of all minor roads during the formation of the congestion, while speed decreased from 52.6 km/h to 15.9 km/h. After the increase of the congestion, the speed remained within the range of 11.6-16.5 km/h, while the vitality fluctuated widely between 32% and 64%.

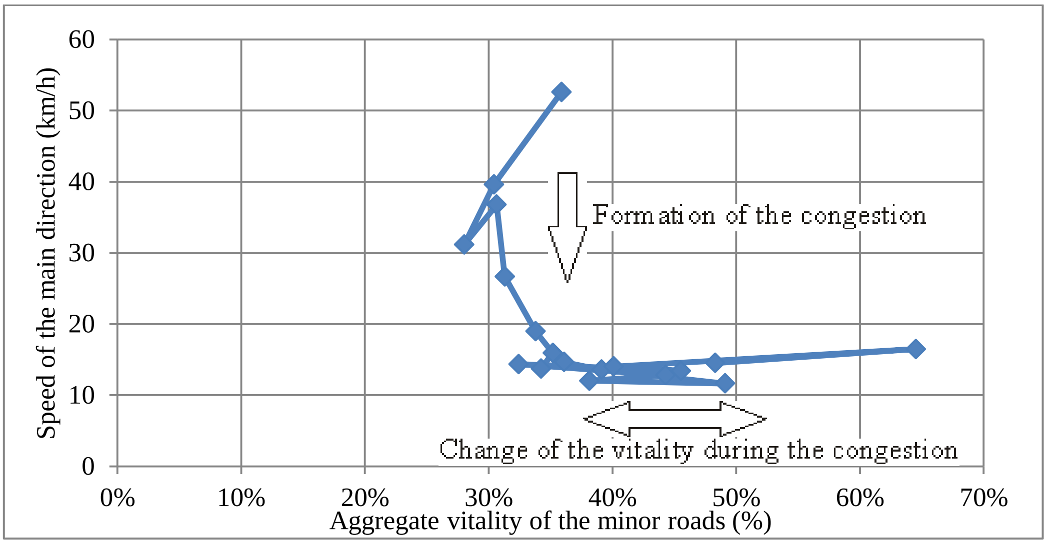


Fig. 6.
The relationship between the speed of the main direction and the aggregated vitality of the minor roads during the congestion on Egér Road, Budapest

Considerable changes were observed on Balatoni Road during the formation of the congestion (Fig. 7.). Speed and vitality decreased almost equally, with considerable fluctuations in both. The speed reduction from 45.6 km/h to 14 km/h was parallel to the growth in aggregate vitality from 27.9% to 48.1%. In this case as well, speed remained within the range of 10.9-6.2 km/h even after the building up of the congestion, while vitality fluctuated widely in the range of 33.7% to 67.7%.

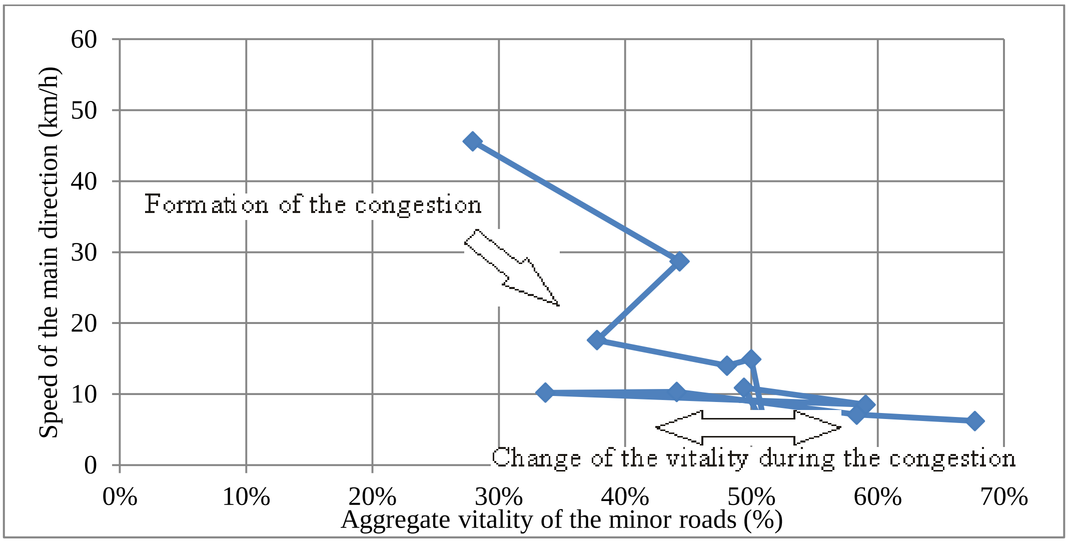


Fig. 7.
The relationship between the speed of the main direction and the aggregated vitality of the minor roads during the congestion on Balatoni Road, Diósd

5. Discussion

According to the research, the role of the directions also changed in addition to the speed of the main direction during the formation of the congestion. There is a close, not thoroughly clarified relationship between the aggregate vitality of minor directions and the speed of the main direction, and consequently the degree of the congestion. Simultaneously to the decrease in speeds of the main direction, the aggregated vitality of the minor directions increased from around 30% to around 70%. At the same time, the speed of the main direction decreased from 45-50 km/h to 5-12 km/h. During the formation of the congestion in the first examined case, the decreasing of the speed occurred without a change in vitality. In this case, the increase of the traffic volume in the main direction probably slowed the main direction, then the minor directions could ingress very effectively into the low-speed main direction. In the other examined case, the decrease in speed was parallel to the change in vitality. It is assumed that the increasing rate of the minor direction contributed to the slowing of the main direction. The most important observation is that the aggregated vitality of the minor directions is generally very high and variable at the low speed of range. The very narrow range of speed of the congestion and the similar vitality and speed values of the two fundamentally different examined road sections are remarkable. During the formation of the congestion and during the congestion itself, vitality can change significantly. This change characterised the vitality. Based on detailed research, it is advised to classify vitality.

6. The vitality of traffic directions in traffic design

The concept of vitality quantifies the difference and the change of traffic routing under congested and normal traffic conditions on road networks with recurrent congestions. The change of traffic routing and the existence of the minor directions with excessive vitality indicates the inadequacy of current road network traffic designs and questions state-of-the-art traffic regulations and traffic design methodologies. Cutting back minor directions with excessive vitality is essential to the success or failure of the traffic design. Excessive vitality could principally be limited by the capacity distribution of the intersection traffic design. Significantly slowing rat-run traffic could play an important role in the limitation of excessive vitality. The declared strategic objective is to secure the adequate vitality of the congested main direction. Including the vitality of the traffic directions into the traffic design process provides a new and effective congestion-related tool. This tool could play a key role in making effective urban traffic control strategies both on the strategic and on the tactical level. The development of the detailed methodology is therefore justified.

7. Conclusions

The concept of the vitality of traffic direction was defined. On road networks with recurrent congestions, the aggregated vitality of the minor directions and the speed of the main direction are closely linked. The specific characteristics of this connection deserves additional consideration. The vitality of minor directions helps us clarify the role of traffic directions. The findings imply that the designing of road networks with recurrent congestion should include the effects of the vitality of minor traffic directions. The elaboration of a toolkit is an urgent issue. Another important challenge is to set the territorial division of the road network to be designed and the definition of the design targets.

References

Bell, M.G.H.; Bonsall, P.W.; Leake, G.R.; May, A.D.; Nash, C.A.; O'Flaherty, C.A. 2006. *Transport planning and traffic engineering,* 500 p.

Garber, N.J.; Hoel, L.A. 2009. *Traffic and highway engineering*, 250-263.

Goodwin, P. 2004. The economic costs of road traffic congestion, Discussion Paper pp. 2.

Hobbs, F.D. 1979. *Traffic planning and engineering.*

Lighthill, M.J.; Whitham, G.B. 1955. On kinematic waves II: a theory of traffic on long crowded roads, *Royal Society of London*, 317-345

OECD, ECMT, 2007. Managing urban traffic congestion, Summary Document, 10-25.

Vörös, A.; Szele, A. 2005. Causes and ameliorating methods of traffic jams on the northern section of the Grand Boulevard in Budapest, *Urban Traffic 2005/1.*

TRANSPORTING GOODS BY FOOT – AN APPROACH FOR URBAN AREAS

Volker Hartl-Benz[1], Petra Matzenberger[2], Bernhard Rüger[3]

[1,2] *Vienna University of Technology, Institute of Transportation, Research Centre for Railway Engineering, Traffic Economics and Ropeways, Vienna, Austria*
[3] *St. Pölten University of Applied Sciences, St. Pölten, Austria*

Abstract: There's plenty of traffic in today's urban and suburban areas. Although of course the car still has a high share of the modal split, much of this traffic is done by foot, bicycle and by means of public transport. Especially traffic by foot is one of the most important modes of transport in urban areas, often largely underestimated. What if we could use this already existing traffic, especially if it is done in an environmentally friendly way, to transport small goods? The exploratory project "GutZuFuß" ("*Transportation by foot*", founded by the Austrian Ministry for Transport, Innovation and Technology and the Austrian Research Promotion Agency) wants to find out if such a system is realizable, and if yes, under which conditions and requirements. Caused by increasing online-shopping activity and the tight networking of the business world, the amount of transported small goods is growing in the private sector as well as in the area of B2B-operations. "*Transportation by foot*" works as an electronic interface between a registered person who is on her/his way and a client (private or company), who has to ship a good. As a first step, due to the complexity of the problem and in order to minimize risks, extensive customer surveys were conducted. Learning more about the customer's interests and needs should help to establish an attractive goods transportation service by using already existing mobility in urban and suburban areas, accepted by the customers and focused on their needs. This article presents the results of the surveys and gives an outlook what they mean for the future of the project.

Keywords: cargo transport, public goods transport, environmentally friendly, traffic reduction, traffic by foot, needs and requirements, customer surveys.

1. Introduction

Transportation by foot has the goal of using already existing, active and sustainable passenger mobility for small goods transport in cities. The system will connect (for example via smartphone app) persons or companies that want to send small parcels or letters with people who are traveling. Due to the large number of people who are traveling in cities, flexible and fast delivery could be one of the strengths of the system. The project aims to analyze whether and under what conditions the existing active and sustainable mobility may be merged with the need of small-parcel-dispatching.

1.1. Problem and Objective

How should a system like *Transportation by foot* be designed so that it is accepted by potential customers? To clarify this issue, in order to get more knowledge about the frame conditions and success-preconditions for such a service, it is necessary to know something about the interests of potential customers. The aim of this project step is therefore the collection, analysis and interpretation of the wishes and needs that different user groups have on a system like *Transportation by foot*.

1.2. Method

For learning something about the requirements of potential users of the system *Transportation by foot* - customers as well as those offering transport services – surveys by questionnaire were conducted from December 2015 to February 2016. The interviews were held in streets and in certain areas of metro stations. Overall, 675 people were interviewed.

2. Results of the survey

2.1. Basic information

Below, the most important results of the survey will be presented. The number of respondents ("N = ...") noted in the various diagrams varies from chart to chart, as not all respondents answered all questions.
The gender distribution shows a clear imbalance in favor of men: 61% of respondents are men, 39% women. The reason for this imbalance is unclear.
Except for the group of 15-19 year olds, the age categories were divided in ten-year-steps, e.g. 20-29 years, 30-39 years, etc. Almost one third of respondents are between 20 and 29 years old. Slightly less than 20% are each between 30 and 39 and between 40 and 49 years old. The rest of the respondents are distributed among the other age groups, the proportion of each is in the single digits. With rising age, the number of respondents drops.

[1] Corresponding author: volker.hartl-benz@tuwien.ac.at

Most respondents have a job: 43% in full-time, 13% part-time. 28% of respondents are students, 8% pupils. 11% are retired. 3% are unemployed. For this question, multiple answers were possible, i.e. it could for example a student also have a job.

As the reason why they were traveling at the time of the interviews, 25% of respondents said they were on leisure activities. Slightly less, namely 23%, were on the way to or from work. Each just under 20% were on the way to shopping or to certain places such as post office, office, library, etc. 12% were on way to or from their place of education. 4% of respondents said they were on the way to or from medical appointments.

2.2. General results

On the fundamental question of whether a person wants to participate as a customer in *Transportation by foot*, the respondents answer as follows (see Fig. 1):

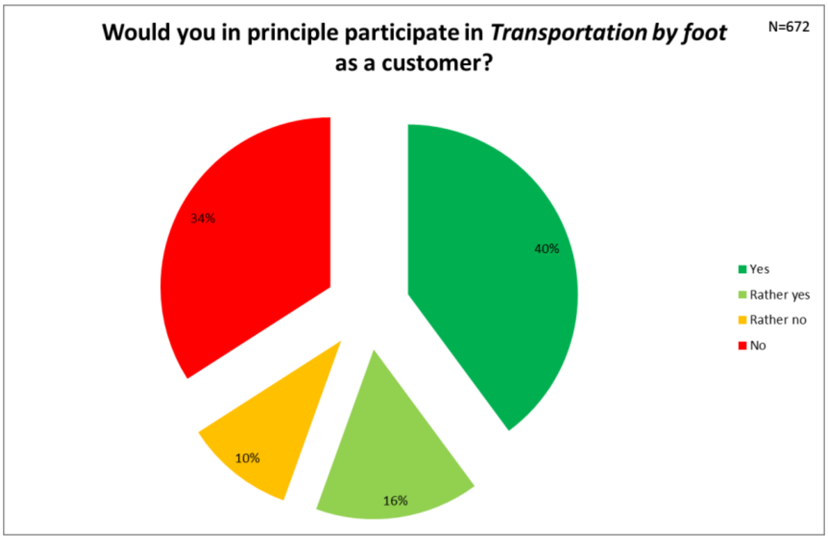


Fig. 1.
Participation in Transportation by foot as a customer

Participation as a customer means to receive a packet from a person who works for the system. Just over 50% of respondents can imagine participating in the system in this way.

The benefits that customers see in *Transportation by foot* are shown in Fig. 2. The greatest benefit of the system is seen in more flexible delivery times and shorter or less routes for the customer. But also "fast delivery", "more cost-effective" (as previous systems, note) and "environmental protection" receive widespread support. When it comes to "environmental protection", it has to be considered that the approval to this answer-option may mainly be given because it is seen as socially desirable. "Real-time shipment tracking" and above all "personal relations to deliverer" experience lesser support.

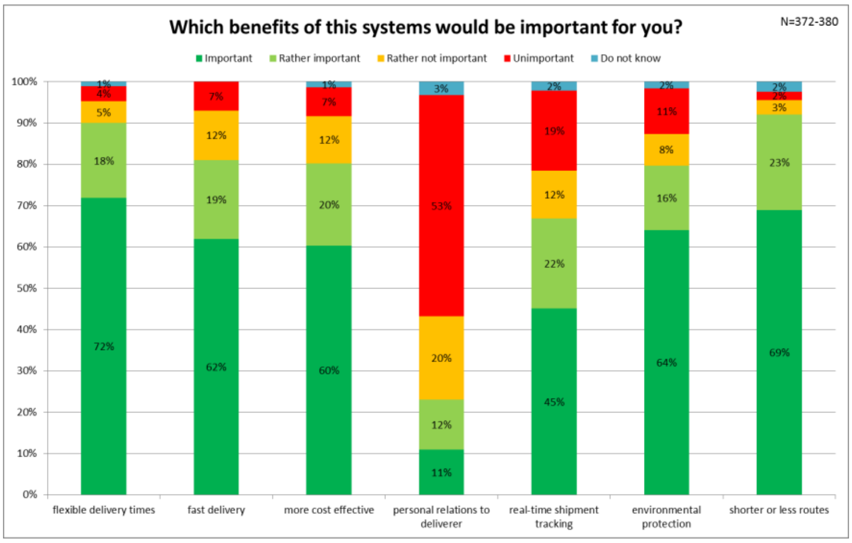


Fig. 2.
Benefits for customers

About 40% of respondents can think of active participation in *Transportation by foot* as the carrier of (small) shipments (see Fig. 3). 47% clearly rule this out; further 12% tend to rule out active participation.
Which packages would be transported by those who have an interest in participating actively? 95% say they would transport small packages. Letters would be picked up by 67%, food purchases by 51%. 43% say they would also transport fragile items. Unsurprisingly, substantially sized packages experience the slimmest willingness to transport: Only 24% said they would pick them up.

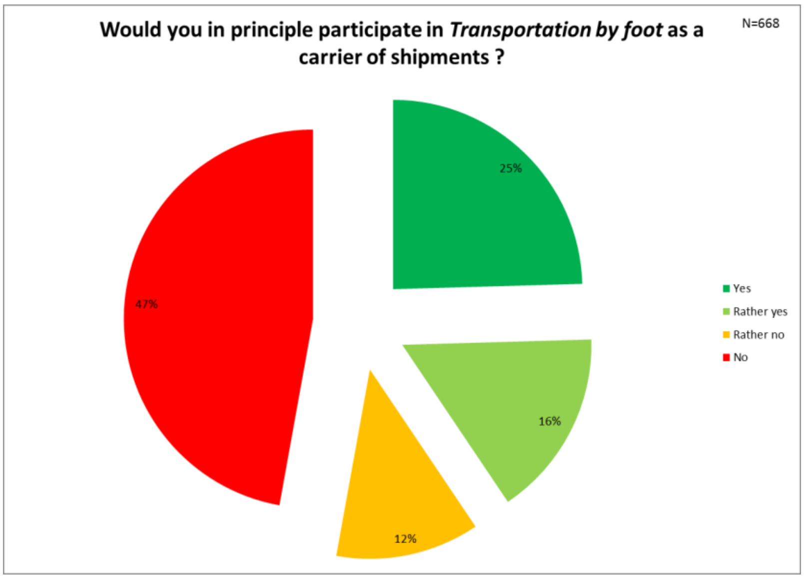


Fig. 3.
Participation in Transportation by foot as carrier of shipments

An important question is: What motivates people to participate actively in *Transportation by foot* as carrier of packages. This is a key point especially for any real implementation of the system. Fig. 4 reveals:

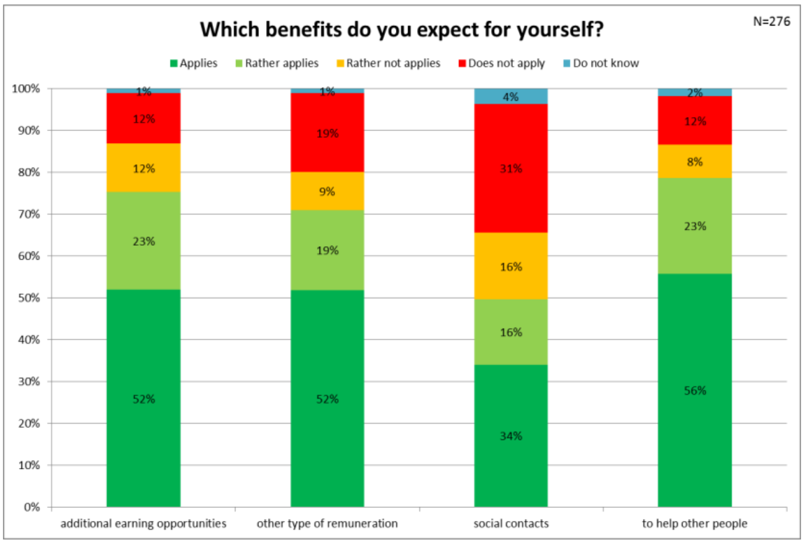


Fig. 4.
Expected benefits of Transportation by foot when participating as a carrier of shipments

Evidently, the three answer choices "Additional earning opportunities", "Other type of remuneration" and "To help other people" each experienced about the same high levels of agreement. The answer choice "Social contacts" (meaning the social interaction in the packet transfer) drops significantly in contrast. Attention is given to the answer choice "To help other people" in the interpretation of the result. With a total of almost 80% this answer option received the highest approval to the question of what benefits one personally sees for himself as a carrier at *Transportation by foot*. But here there is again the possibility of the influence of social desirability, i.e. respondents give a certain answer not because they are actually of this particular opinion, but because they believe that this particular answer is expected of them.
"Other type of remuneration" means primarily a kind of service exchange. For example, it is conceivable that a person in exchange for the delivery of a package provides a service such as help with shopping, household or working in the garden. A further stage of expansion would be the introduction of a credit system, allowing to compensate the varying

efforts of the different activities (e.g. three deliveries of shipments correspond with once helping with gardening, etc.). The idea of the service exchange was discussed but not elaborated in detail within the project *Transportation by foot*.
Fig. 5 shows the obstacles that could occur at the recruitment of active participants. Only 51% and 63% respectively agree completely or rather with GPS positioning. However, a positioning system like GPS is a prerequisite for the operation of the system. The registration of all participants is also a basic requirement, and with a total of 86% it experiences a substantially higher compliance than GPS. With 85%, the vast majority of respondents agree with the entering of houses with more than one flat. Although this is not a necessary prerequisite for the system, it is helpful for practical implementation in any case.
The most interesting and perhaps most critical point is the agreement to additional spent time at pickup and delivery of shipments. 52% (of those who have an interest in participating actively as carrier) clearly agree to invest some time; another 27% rather agree. Here it may be assumed that it depends very much on the extent of the additional time required, whether it is accepted or not.

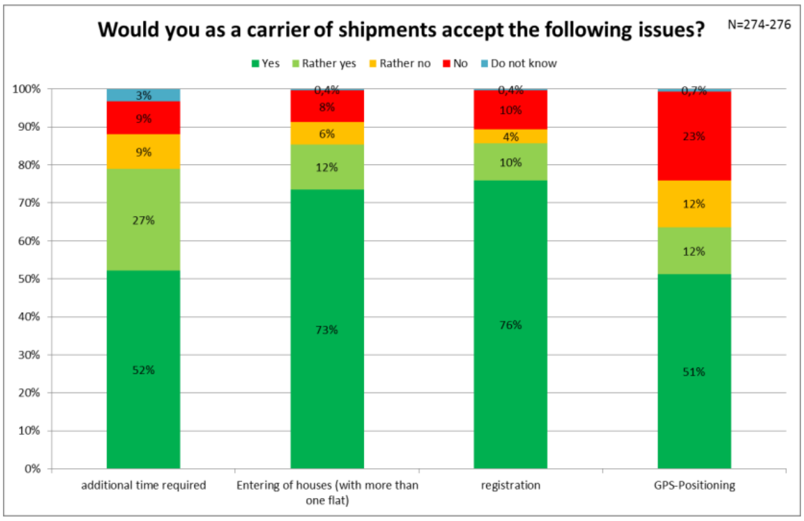


Fig. 5.
Approval with certain issues

Time is a critical factor! This is also shown in the answers to the question what reasons there are to not participate as a carrier of shipments. This question was only asked to persons who showed no willingness to participate as a carrier. The main reason not to participate is the belief of not having time for it. 58% say that they agree, a further 9% rather agree. Thereby "I have no Time" is by far the most important reason to not participate in *Transportation by foot*. Other reasons include the worry of being unable to deliver the shipment at the destination (22% "agree", 19% "rather agree"), reservations due to the unclear legal situation (26% "agree", 13% "rather agree"), a rejection due to a feeling of great responsibility (22% "agree", 16% "rather agree") and the already mentioned refusal of a GPS positioning (31% "agree", 4% "rather agree") by some people.
A concept like *Transportation by foot* must meet certain frame conditions in order to be attractive to people. Fig. 6 shows some of the issues that are expected. 97% of those who have interest in participating either as a consumer or as a carrier want legal protection regarding the transported goods. This means that the carried package should be assured against loss or damage. The participating individuals do not want to bear the risk by themselves. Also, a high percentage of 94% expect safety, for example in terms of transport of consignments (e.g. dangerous goods) or regarding the smooth handover of shipments at start and finish. This requested safety could for example be achieved by the compulsory registration of all participants. A fallback system if the recipient is not there and the package carrier is unable to deliver the consignment is expected by 95%. This would help to avoid that someone is forced to keep a package by himself. When asked whether they expect an evaluation system, 52% say this applies and another 23% say it rather applies. Although the agreement to this proposal is significantly lower compared to the others, a rating system can still be very useful. It can strengthen the trust in the system. Recipients of shipments could rate the carrier for punctuality, reliability etc. and vice versa. These reviews should be visible to all participants in *Transportation by foot*. This would be a strong incentive for all parties to actually keep to agreed times, places etc.

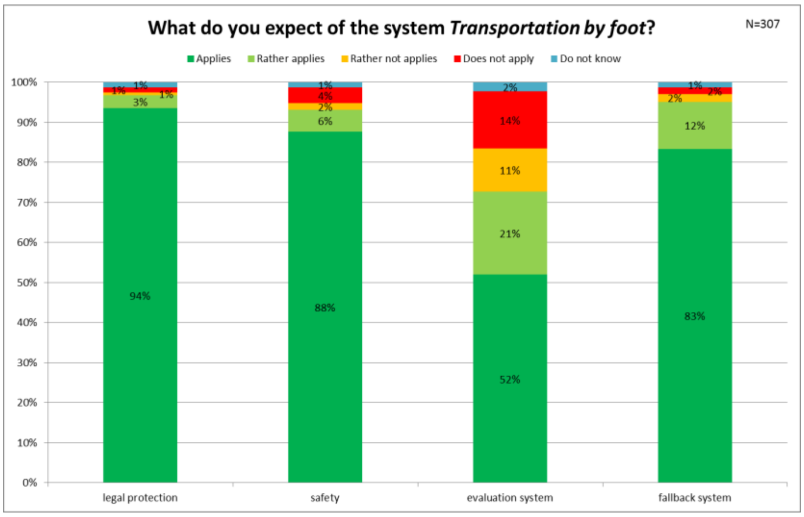


Fig. 6.
Expectations of the system Transportation by foot

2.3. Results from individual groups

<u>Effect of age of respondents:</u>
Surveys in previous projects have shown that younger people are often open about new ideas; older people face such ideas rather skeptically. *Transportation by foot* is no exception in this regard. In both the participation as customers and as carrier of shipments, younger people show significantly more interest than older ones. So 68% of 20-29-year-old would participate as customers in *Transportation by foot*, but only 45% of 60-69 years and only 26% of 70-79-year-old would do so. The picture is very similar when it comes to the participation as a carrier of shipments. 55% of 20-29-year-old would participate as a carrier, but only 29% of 60-69-year-old would do so (and even only 8% of 70-79 year olds).
The questions about the benefits of the system show a different picture. In some cases both the benefits for a customer and for a carrier of shipments is estimated lower with rising age. Such is the case with the benefits of fast delivery, real-time shipment tracking and additional earning possibilities. In most cases, age has no influence on the perception of benefits. And in some cases, the benefit is estimated higher with age, e.g. the benefits of personal contacts and the possibility of another form of compensation. As explained above, this could be a kind of service exchange by providing help with craft activities, purchasing etc. (see Fig. 7). This point deserves special attention because it is obviously a way to appeal to those who at first glance see little benefit for themselves in *Transportation by foot*.

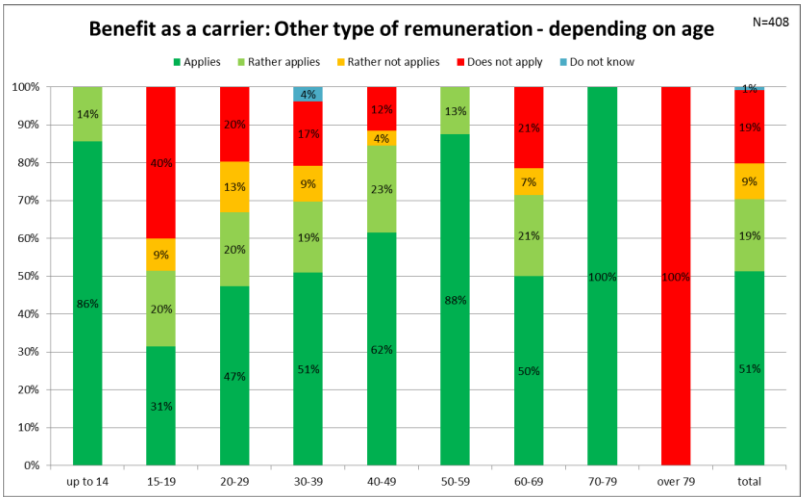


Fig. 7.
Benefit as a carrier: Other type of remuneration, depending on the age of respondents

Age does not have much influence on the approval of certain issues and on what people expect from the system. One can only mention that a rating system is expected relatively more by the younger age groups.
If one analyses the reasons why people don’t want to participate in *Transportation by foot* (e.g. "I have no time" etc.), interesting results are obtained. The approval rates to nearly all of these reasons decline with increasing age. Particularly from the age of 60 years on this effect can be observed. There was no reason not to participate in the system which showed an increase in approval with age.

This means that the elderly, although less interested in *Transportation by foot* than the young, have fewer reservations and fears about the system. Perhaps the low interest is therefore only due to an initial skepticism about a new idea, and potential is also available in the long run among the elderly population.

Influence of employment of respondents:

Respondents were also asked about their employment. The categories were full-time employment, part-time employment, student, pupil, housekeeping (without employment), unemployed, pensioner, military or civilian service, apprenticeship and parental leave. The results for people on parental leave, persons who are engaged in housekeeping, military and civil service as well as for apprentices have to be interpreted with caution, as the sample size of these groups includes only a few people.

When asked about participation in the system as a customer, part-time workers, pupils and students showed high interest relative to the average. Lower interest among full-time workers, the unemployed and pensioners were identified. One hypothesis for this result is that the groups that have actual or subjectively perceived less free time available are less interested in participating than the groups with actual or subjectively perceived more free time. This hypothesis is supported by the fact that of the people who do not want to participate in the system as a carrier, 73% of full-time workers say they are unable or unwilling to participate in *Transportation by foot* due to time constraints. Among part-time workers only 55% list this reason, among unemployed 40% and among pensioners 54%.

However, the unemployed and pensioners as outlined previously are also the groups that have little interest in participating as a customer in the system. However, the disinterest of pensioners is mainly connected to age as explained above. The low interest of unemployed people remains unclear.

However, when asked if they would participate as a carrier of shipments for *Transportation by foot*, among the group of unemployed 37% answered "yes" – giving them first place, although this result is put into perspective by the low number of "rather yes" answers (5%). Compared to the average there is also high interest among part-time workers (30% "yes", 23% "rather yes"), pupils (36% "yes", 20% "rather yes") and students (32 % "yes", 24% "rather yes"). The smallest interest is among pensioners with 16% "yes" - and 5% "rather yes" - answers.

Additional earning opportunities are especially important for students (65% "agree", 31% "rather agree") and the unemployed (88% "agree", 12% "rather agree"). For unemployed people the importance of social contacts is above average (63% "agree"). The majority of unemployed people also agree to additional time requirements (88% "agree", 12% "rather agree"), while the majority of students and to a slightly lesser extent the full-time employed are more skeptical.

Influence of gender of respondents:

The effects of gender on the answers in this survey are rather low. Both in participating as a customer as well as a carrier, women show slightly greater interest than men. Also concerning the benefits derived by *Transportation by foot*, women see slightly greater benefits for customers in all points than men. The one exception is the personal contact with the deliverer. In this aspect men see more benefits. The benefits of *Transportation by foot* as carriers are estimated to be slightly higher by men in all issues.

The answers on consent to certain points, the expectations of the system and the reasons against participation are practically identical between men and women. Not being able to drop off a shipment at the destination is the only concern where women show slightly higher percentage than men. Accordingly, more women than men also expect a functional fallback system for such cases. Finally, it is striking that women showed significantly more fear of dangerous goods carried than men (men 28%, women 40%, total 33%).

3. Conclusion

Transportation by foot would make use of existing personal mobility in cities for transporting small goods. The system connects (for example via smartphone app) individuals or companies who want to send a shipment with people currently travelling or planning to do so in the near future. Due to the large number of people who are traveling in cities, flexible and fast delivery could be one of the strengths of the system.

To study the needs and desires of potential participants in *Transportation by foot*, extensive surveys were conducted. Each around half of the respondents showed a basic interest in participating as a customer or carrier of shipments. The deciding factor is the existence of a functioning payment system, which provides monetary incentives as well as new, alternative payment options (e.g. service exchange) to increase attractiveness.

By analysis of the surveys it became clear that time is a very precious resource. A realistic chance for the participation of a larger number of persons is only given when participation is managed with a minimal amount of time required. Good organization and knowledge of the package carrier routes and especially the organization of the package transfers are prerequisites to ensure operation. Other basic requirements include registration of all participants, the legal protection (insurance) and a fallback system, should a shipment not be able to be delivered.

Young people show greater interest in the idea of *Transportation by foot* than the elderly. But older people see quite a benefit in certain points. Fears and reservations about *Transportation by foot* are even less pronounced among the elderly than among young people. In particular, the benefits of an alternative type of compensation are appreciated with increasing age, for example means of exchange of services by helping with handiwork or shopping. So it could be possible to appeal to the older population with a thoughtful and tailored to their needs concept. Due to lower fears and reservations, the conclusion can state that the interest of the elderly for *Transportation by foot* will increase once the system has been introduced and become generally known.

Examining employment shows that the interest in participating in *Transportation by foot* is greater among people who have actual or subjectively perceived more free time, such as part-time workers, students and unemployed people. A focus on these groups - at least for the active participation as a carrier of shipments - is worth considering.

Acknowledgements

The project *Transportation by foot* (“GutZuFuß”) is founded by the Austrian Ministry for Transport, Innovation and Technology and the Austrian Research Promotion Agency.

References

There are no external references. The whole paper is based on the internal project results including surveys.
(Project “*Transportation by foot*” --> http://GutZuFuss.netwiss.at)

TRANSPORT MODELLING OF CITIZENS EVACUATION

Martin Šustr[1], Radovan Soušek[2], Alois Koloničný[3], Vladimír Němec[4]
[1] *Department of Transport Technology and Control, Jan Perner Transport Faculty, University of Pardubice, Pardubice, Czech Republic*
[2,4] *Department of Air Transport, Faculty of Transport Sciences, Czech Technical University, Prague, Czech Republic*
[3] *Department of Transport Technology and Control, Jan Perner Transport Faculty, Pardubice, Czech Republic*

Abstract: There is presented a software product intended for evacuations by using road transport while keeping to all the binding conditions. This software displays all the points important for evacuation and its process by means of digital maps puts out routes in dependence on an extraordinary event. It is possible to manually control inputs, parameters and process of the solution.

Keywords: evacuations, software, road transport.

1. Introduction

One of the basic means for saving a human life is an escape (or evacuation) from affected area to safer area. In the occurrence of an extraordinary event (which endangered human life or health) is necessary to decide about evacuation or about another sheltering process. This decision depends on the responsible authority. From the realised analyses is no doubt that evacuation of citizens or group of persons is a basic mean for saving human lives. Moreover, evacuation could be necessary at every moment in every place.
An evacuation could be characterised like a transfer of endangered persons, animals or endangered things from designated area. In the basic form, evacuation is characterised like a summary of activities including management and realisation for timely and good organised moving of citizens, moving of necessaries, moving of animals etc. It could be realised during the peacetime or during the war or state of emergency, too. Evacuation is organised moving of persons, animals from the definite area. Stay in that definite area could be caused serious injury or restriction of living conditions (Soušek, 2008; SSHR, 2015; The Czech Ministry of Transport, 2011, Matuška, 2010).

2. Definition of areal evacuation system

With the controlled long-time evacuation of the large area occurred problem about moving of demanded numbers of persons (or animals, or necessary thing) in the possible shortest time period in the definite area. For this evacuation should be used all available transport means. During evacuation, persons are concentrated in the evacuation centres. They are transported from evacuation centres to the reception centres. These reception centres could be situated near the short-time emergency accommodation.
For management during evacuation is necessary to know input data about:

- Transport network ,
- Location of evacuation centres and reception centres,
- Location and capacity of the short-time emergency accommodation ,
- Numbers of evacuated persons,
- The structure of rolling-stock, numbers and capacity of vehicles, location of vehicles.

Like a next step is a necessary draft of evacuation routes with sufficient capacity. On these routes, evacuation will be realised. The solutions are optimal location of evacuation centres to short-term emergency accommodation. Like criteria for the location could be used the distance between definite places or time for transport between these places. Furthermore, is necessary solve allocation of transporting vehicles (stands or garage places) for definite evacuation centres (it is necessary for minimalizing of vehicles delivery delay) (Kamenický et al., 2011; Szabo, 2015; Soušek et al., 2011; Soušek and Viskup, 2011; Fuchs et al., 2015).

3. Modelling of the long-term areal evacuation

For finding another input of data and evacuation process realisation is necessary to use minimum paths search algorithm on the transport network.
Upgraded Danzig algorithm can be found minimal path length, the approximate time for passing, as well. Algorithm is suitable for using distance like criteria (length of minimal path) or time for passing like criteria. For calculation of driving time could be used planned time of passing on designated roads (definite by the class of the road). In this algorithm is easy to use for riding ban on selected paths. With these banned paths algorithm couldn't calculate due to some restrictions on operation.
Like a data input for evacuation is an information about numbers of evacuation centres m with numbers of evacuated persons $a_1, a_2, \ldots, a_m$ and n numbers of short-term emergency accommodation places with capacity $b_1, b_2, \ldots, b_n$. Location of the bus garage (bus stand) $c_1, c_2, \ldots, c_k$ is included, too. These data are pasted in the matrix. First matrix X is

[1] Corresponding author: martin.sustr@student.upce.cz

pasted evacuation centres with places of short-term emergency accommodation for the consumer. In this matrix is solved allocation of evacuation centres to the accommodation (reception centres). In the second matrix Y is bus stand (or bus garage) like a supplier for places of short-term emergency accommodation (the placing of buses for the definite centres). The capacity of garages $c_1, c_2, \ldots, c_k$ are well known and the need for individual evacuation centres $d_1, d_2, \ldots d_m$ will be settled by evacuation manager.
Like criteria in both matrix could be used the time for movement between this places with the capacity respecting. For solution is necessary equality between needs on the consumer side and capacity on the supplier side. This problem could be used by the *simulated supplier* or *simulated consumer*. In the matrix X is not possible to create simulated (fictional) member (any person couldn't stay in evacuation centres. It is necessary to be valid:

$$\sum_{i=1}^{m} a_i \leq \sum_{j=1}^{n} b_j \tag{1}$$

The numbers of evacuated persons must be same or smaller than the capacity of all property for emergency accommodation. In the cases:

$$\sum_{i=1}^{m} a_i < \sum_{j=1}^{n} b_j \tag{2}$$

Create a factious supplier with capacity

$$a_{m+1} = \sum_{j=1}^{n} b_j - \sum_{i=1}^{m} a_i \tag{3}$$

In the matrix Y is necessary to take in the account limitation in a number of buses for individual evacuation centres (it couldn't exceed the total number of vehicles). In this case valid:

$$\sum_{i=1}^{k} c_i \geq \sum_{j=1}^{m} d_j \tag{4}$$

For cases that Eq. 4, will be added to the matrix factious consumer with demand

$$d_{m+1} = \sum_{i=1}^{k} c_i - \sum_{j=1}^{m} d_j \tag{5}$$

For optimisation of X matrix and Y matrix is available Danzig algorithm. Optimisation of evacuation centres allocation to the places of short-term accommodation centres and allocation of vehicle garage to the evacuation centre is realised by that. The calculated value of movements (in matrix X) is numbers of evacuated persons from evacuation centre to the short-term emergency accommodation centres. Values in Y matrix are a number of buses from i-garage to j-evacuation centre.
The evacuation coordinator, try to minimise total time for evacuation process. The basic allocation of the object couldn't be optimal (because there is a lot of necessary movements between centres), Therefore is defined optimal location and allocation of objects and means, but this location couldn't be optimal with accordance numbers of journeys which are necessary for the move of all persons between objects. The decision about evacuated persons from evacuation centre to the short-term emergency accommodation is necessary to divide to the two phases.
In the <u>first phase</u> number of persons are replaced by an integer number of buses (capacity of buses). The number of buses must cooperate with a number of persons in an evacuation centre. The volume of transport in this assign matrix is information about total seat capacity or about transported persons (after multiplying with numbers of seats) from evacuation centre to the short-time emergency accommodation centre. A number of persons transported in the first phase are subtracted from the number of persons in evacuation centres and available places in place of accommodation. The number of persons in evacuation centres after the first phase is smaller than the capacity of one vehicle.
<u>The second phase</u> of the solution is about the placement of remains persons in evacuation centre of the free capacity in short-term emergency accommodation. For the second placement is possible to change the charge of the journey between evacuation centres and accommodation places. It is applicable for minimization of journeys numbers. Volumes calculated in the second phase are added in the volumes in the first phase and it is a complete assign of evacuated persons by Danzig algorithm.
In the basic of the calculated values, distances, travel times, etc., between individual points, etc. is solved continuance of evacuation. Total time of evacuation for one vehicle t_{e1} is consist of time for ride from time to depart t_v, time for ride between garage and evacuation centre t_{ges} time for Getting of persons t_{nc} time for journey from evacuation centre to the place for short-term emergency accommodation t_{esmnu}, time of getting-out person $t_{vc,}$ time for ride between place of

accommodation to garage t_{mnug}. Time for getting-on t_{nc} and getting-off t_{nv} depends on numbers of passengers and the average time for getting-on (getting-off) for one person. Total time for one evacuation vehicle is:

$$t_{e1} = t_v + t_{ges} + k \cdot (t_{nc} + t_{esmnu} + t_{vc}) + (k-1) \cdot t_{mnues} + t_{mnug} \qquad (6)$$

Where; k: a number of journeys between evacuation centre and accommodation centre. The value k depend on numbers of evacuated persons, numbers of used vehicles and on the capacity of vehicles. The total time of evacuation for all evacuation centres equals to the maximal time of individual vehicles using (GA 103/03/1077, 2004; Soušek and Kasal, 2013; SSHR, 2015; Hrůza et al., 2014; Dubec and Hrůza, 2012).

The continuity of evacuation must be solved in one time for all vehicles. Algorithm about continuity of evacuation could be in the form:

1. Evacuation announcement (start); time 0,
2. The time between announcement and departing from garage – time of depart,
3. Arrival to the evacuation centres – time of arrival,. From the total number of the person in i-evacuation centre is subtract capacity of the vehicle. If is there fewer persons that capacity of the vehicle, subtract that number,
4. A number of persons multiply time of getting-on of one person → Result is dwell time and by the dwell time could be found time of depart from an evacuation centre,
5. Time of arriving to the short-term emergency accommodation centre,
6. A number of persons in vehicle multiply time of getting-off of one person → Result is dwell time in accommodation centre and by the dwell time could be found the time of depart from accommodation centre. Check of person, whether is still necessary go to evacuation centre:
   - A. If yes: in evacuation centre will be reserve proper number of persons. The vehicle will travel back to the evacuation centre and the algorithm continues with step no. 3.
   - B. If no: vehicle goes back to the garage.
7. Time of arriving to the garage is recorded.
8. Total time of evacuation is the maximal time from individual operation times of vehicles.
9. End

4. Software model for solution

The software is a graphical environment for a map of road network edit, for pasting important point for evacuation planning and for evacuation process management. Graphics outputs of that program could be printed of exported in BMP or JPEG format.

The core part of the software is digital maps of the area. These maps are saved in ESRI Shapefile format (for the ESRI Browsers). For the minimal path, algorithms are necessary to edit data to the graph theory logic (especially about the description of the graph: the edge of the graph is a connection of two incident vertexes). In this data are not included cross (vertex of the graph) and therefore is necessary create an algorithm that the crosses found on the map. After finding the vertexes and incidence assignment to the edges of the graph was there another complication for data use. The curves (individual roads) not correspond with vertexes. It was also necessary to decide about incidence with vertexes and assign them the correct information about incidence with vertexes. Function for that assignment and data editing are an integral part of the software. Information about the geographical location of individual points, curves are saved in the coordinate system S42, it is another advantage of the digital data. This system identifies distance by the coordinates X and Y from the imaginary point [0,0]. Thank this method, the geographical identification of individual points and distance between that points can be calculated, very easy (GA 103/03/1077, 2004; The Czech Ministry of Transport, 2011; Szabo, 2015; Soušek et al., 2011; Pitas et al., 2014; Fuchs et al., 2015; Říha and Tichý, 2015).

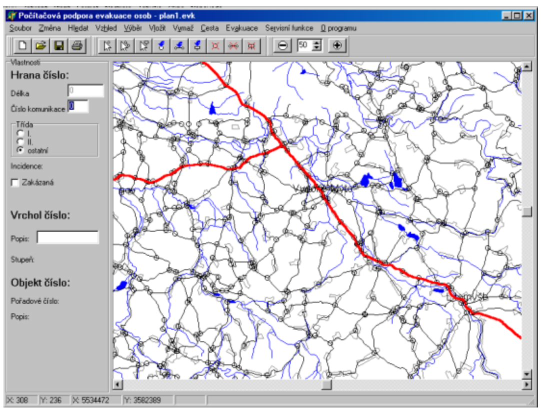


Fig. 1.
Software
Source: Authors with using software

The program is typical for Microsoft Windows (control by mouse and keyboard, like another application created for Microsoft Windows environment). Access to the individual functions of the program is possible through the application menu.

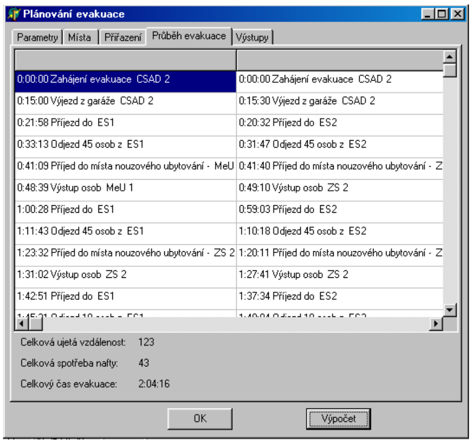


Fig. 2.
Process of evacuation
Source: Authors with using software

5. Conclusion

For planning and decision making during a crisis situation is software one of possible auxiliary and support tool. Software support allows making a decision in limited time with evaluation of the large volume of information.
The process of transport ensures planning for evacuation can be automatized with mathematical modelling followed by a software solution.
Currently, any tool is not used for planning of evacuation. By the author's opinion it a detrimental, because software solution can help with planning in the financial cost and reaction speed.

References

Dubec, R.; Hrůza, P. 2012. Military Concept of Modularity, *Croatian Journal of Education*, 14(1): 35-41.
Fuchs, P.; Němec, V.; Soušek, R.; Szabo, S.; Šustr, M.; Viskup, P. 2015. The Assessment of Critical Infrastructure in the Czech Republic. In *Proceedings of the Transport Means 2015, Conference*.
Fuchs, P.; Zajíček, J.; Kraus, J. 2012. Safety integrity versus risk value. In *Proceedings of the 11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference*.
GA 103/03/1077 2004. *Teoretické řešení krizových situací v dopravě – Grantová Agentura České Republiky*, Project no.: GA 103/03/1077: Data mining from research project, Czech Republic.
Hrůza, P.; Soušek, R.; Szabo, S. 2014. Cyber-attacks and attack protection. In *Proceedings of The 18th World Multi-Conference on Systemics, Cybernetics and Informatics*, 1:15-18.
Kamenický, J.; Čermáková, H.; Soušek, R.; Němec, V. 2011. Multiple measurement of physical quantity from the risk evaluation point of view. In *Proceedings of the 15th World Multi-Conference on Systemics, Cybernetics and Informatics*, 212-215.
Matuška, J. 2010. The methodology for designing accessible public transportation, *Transport*, 25(2): 222-228.
Pitas, J.; Němec, V.; Soušek, R. 2014. Mutual Influence of Management Processes of Stakeholders and Risk Management in Cyber Security Environment. In *Proceedings of The 18th World Multi-Conference on Systemics, Cybernetics and Informatics*, II: 94-97.
Říha, Z.; Tichý, J. 2015. The Costs Calculation and Modelling in Transport. In *Proceedings of the Transport Means 2015, conference*.
Soušek R. 2008. *Transport in Crisis Situation; Pardubice*, Institut Jana Pernera, Pardubice, Czech Republic.
Soušek R.; Viskup P. 2011. *New system of reconstruction of railway infrastructure during the Crisis states*, Institut Jana Pernera, Pardubice, Czech Republic.
Soušek, R. 2008. *Doprava v krizových situacích*, IJP, Pardubice, Czech Republic.
Soušek, R.; Kamenický, J.; Němec, V.; Čermáková, H. 2011. Multiple Measurement of Physical Quantity from the Risk Evaluation Point of View. In *Proceedings of The 15th World Multi-Conference on Systemics, Cybernetics and Informatics*, 1: 212-215.
Soušek, R.; Kasal, R. 2013. *Automated complex information system for remote management of crisis the situation in rail transport, with emphasis on critical infrastructure, Normative guidance by Czech National Government*, Czech National Government, Prague, Czech Republic.

SSHR 2015. Methodology of economic measures for Crisis situations. Available from Internet: <http://www.sshr.cz/cinnosti/stranky/metodiky.aspx >.

Szabo, S. 2015. Determinants of Supplier Selection in E-procurement Tenders, *Journal of Applied Economic Sciences*, 10 (7(37)): 1153-1159.

The Czech Ministry of Transport 2011. *Measures for reporting incidents of security Department of the Ministry of Transport no.14/2003, no. ac. 227/2011-030-KR/1, At.4, actualized at 1.11.*, The Czech Ministry of Transport, Prague, Czech Republic.

BANDWIDTH PROVISIONING IN ELASTIC OPTICAL NETWORKS

Suzana Miladić[1,2], Goran Marković[2], Valentina Radojičić[2]
[1] *University of East Sarajevo, Faculty of Transport and Traffic Engineering, Bosnia and Herzegovina*
[2] *University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia*

Abstract: The concept of elasticity has recently emerged as an important research area in optical networking and it is a promising solution to cope with the 100 Gb/s and beyond data transmission in future optical networks. In this paper, we address an offline routing and spectrum allocation (RSA) problem as one of the most important issues of elastic optical networks design. The main idea behind elastic networks is that the spectral resources on each optical link are classified into spectrum slots, where each slot corresponds to an OFDM subcarrier. The main benefits of this approach as well the main differences compared to traditional routing and wavelength assignment problem are considered. We present the RSA research results on a small network topology where we have minimized the number of frequency slots used over all fiber links in the network.

Keywords: elastic bandwidth provisioning, routing and spectrum allocation, frequency slots.

1. Introduction

Telecommunications development has changed its direction in a manner of extending the channel capacity by utilizing the spectrum resources more efficiently and adaptively according to the transmission path characteristics and bandwidth requirements. To provide higher spectrum efficiency and flexibility in the future elastic optical networks, the Orthogonal Frequency Division Multiplexing (OFDM) technology is adopted (Zhang et al., 2012). Since Shannon limit becomes overcome and commercial systems will need to support Tb/s link capacity in the near future (Winzer, 2014), elastic bandwidth provisioning brings new opportunities to meet the increasing capacity requirements and open a new generation of optical networks based on *bandwidth on demand.*

The concept of elasticity allows that some parameters such as modulation format, channel spacing, optical bit rate which have been fixed in conventional WDM networks become adaptable in elastic optical networks (EON, Elastic Optical Networks). With this in mind, ITU-T adapted recommendations G.694.1 and G.872 to include flexibility within ITU standards. The nominal central frequency granularity of 6.25 GHz, the channel width (12.5 GHz) and the concept of frequency slots (FS, Frequency Slots) are defined in G.694.1 (ITU-T, 2012). 12.5 GHz frequency slot is nothing else than the frequency range an optical signal can take. The total spectrum is than divided on FSs and every connection is assigned a different number of slots, so EONs are also called flex-grid optical networks.

The goal of this paper is to address one of the major problem in EONs- RSA (Routing and Spectrum Allocation) and to show that spectrum resources or frequency slots, could be minimized and therefore more efficiently used compared to currently deployed networks. The rest of the paper is structured as follows. Section 2 provides the basic concept of elastic optical networks and differences compared to traditional WDM networks. The RSA problem formulation is presented in section 3. Numerical results obtained by solving the integer linear programming model are shown and discussed in section 4 while section 5 concludes the paper.

2. Concept of elastic optical networks and differences compared to currently deployed networks

Currently deployed optical networks use fixed channel spacing, ITU 50 or 100 GHz, what would not be suitable for future 100 Gb/s and higher bit rates because spectrum will be sized for every demand based on its bit rate and the transmission distance. Also, traffic requirements are typically much smaller than the available capacity so lightpath establishing with small level of utilization is not rational. Considering that traditional WDM networks allow that all demands use the same spectrum what results in capacity wasting, elasticity in EONs is the main difference and this concept overcomes the holes or unused spectrum in large bandwidth paths (depicted in Figure 1).

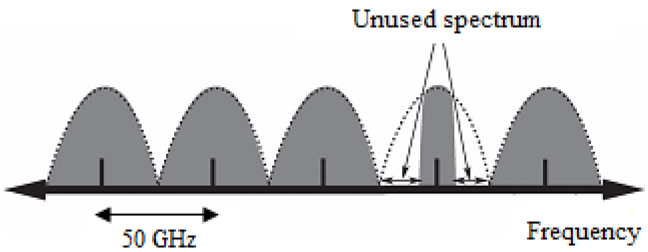


Fig. 1.
Spectrum allocation in traditional WDM optical networks
Source: Chatterjee et al., 2015

The term elastic in optical networks implies optical spectrum dividing in accordance with traffic volume and elastic optical paths establishing or paths with variable bit rates. Chatterjee et al. (2015) described in detail the main

[1] Corresponding author: suzana.miladics@stfdoboj.net

characteristics of such networks: bandwidth segmentation, bandwidth aggregation, efficient accommodation of multiple data rates, elastic variation of allocated resources, reach-adaptable line rate, etc (presented in Figure 2). This area is reaching much attention recently, so there are many opened issues and research challenges. Some of them are discussed in (Gerstel et al. 2012; Talebi et al. 2014; Dantas et al. 2014; Shen et al. 2015).

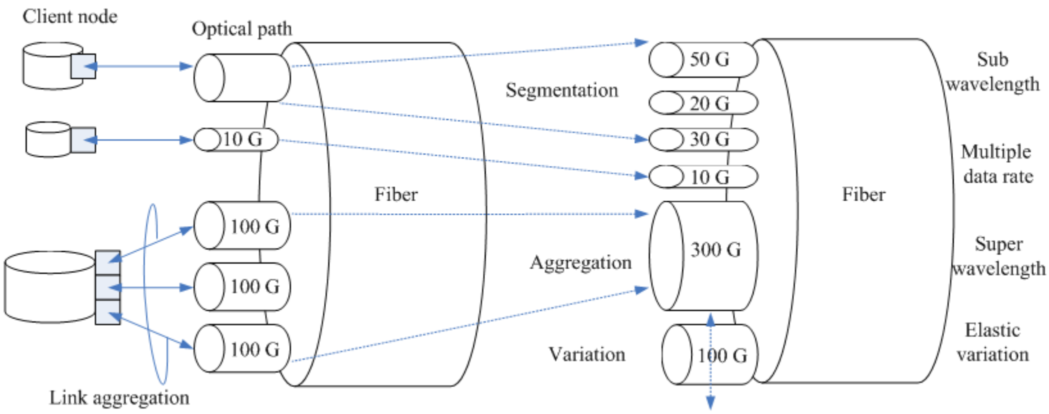


Fig. 2.
Elastic optical networks characteristics
Source: Socrates-Dantas et al., 2014

The major problem in EONs, RSA, is analogue to RWA (Routing and Wavelength Assignment) problem in WDM networks. In RSA, every demand is allocated a different number of frequency slots instead of a whole wavelength. The number of spectrum slots in each fiber link equals the number of wavelengths for any lightpath request. So, if RWA requires 1 wavelength along the lightpath, it is equivalent to a 1 spectrum slot along the lightpath in the RSA problem.

3. RSA problem statement

RSA problem as a generalization of RWA is relatively novel and also could be presented as ILP problem but for networks with large number of slots and demands solution becomes unattainable and heuristics are applied. RSA problem could be splitted into two subproblems: the routing and spectrum allocation subproblem. The first one includes finding the available physical route between a pair of nodes while the second focuses on allocation of appropriate frequency slots around the central frequency or spectrum part to the requested lightpath. Therefore, optical spectrum is quantized into frequency units with appropriate width, for example 12.5 GHz, and signals are modulated on frequency slots in form of subcarriers. Each FS represents an optical channel and, accordingly, an optical path can be established by assigning the required number of contiguous FSs according to the user signal spectrum width.
The main constraints configuring in the RSA statement are the spectrum contiguity and continuity constraint. Spectrum contiguity constraint means that spectrum slots must be placed near to each other and if enough contiguous slots are not available along the desired path, the connection can be broken up into several small demands. Each one of these smaller demands would then require a lower number of contiguous subcarrier slots. The second constraint is equivalent to the wavelength continuity constraint in RWA (continuity of contiguous slots on all links of the path). So, the RSA objective could be defined as: for a given set of demands, the goal is to find the end-to-end optical paths and assign the requested FSs in a contiguous way and to avoid FSs overlapping in network links.
In this paper, we analyzed a static or off-line RSA problem, where traffic demands (each demand corresponds to a connection request) are known in advance. Also, traffic volume is translated into a number of requested FSs (number of subcarriers required for connection) and network has enough capacity to serve all offered demands.
We considered OFDM network as a graph $G = (N, E)$ where N is a set of nodes and E is a set of bidirectional links. A number of FSs is given in each link of the network $F = (f_1, f_2, \ldots, f_{|F|})$. The set of connection requests is denoted with D and for each demand d the source and destination nodes, as well as the number of FSs requested are known (s_d, t_d, n_d respectively). So, a bandwidth demand can be mapped to a certain number of subcarriers or FSs. The list of predefined candidate paths (k- shortest paths) for each demand is denoted with P_d. The total number of paths is P while subset $P_e \subseteq P$ denotes all paths that contain link e.
The ILP model, where some constraints are taken from Klinkowski and Careglio, 2011, but modified with the last one, relies on the following problem variables :
$x_{pf} \in (0,1)$- equal to 1 if FS $f \in F$ on path $p \in P$ is selected to be the lowest indexed slot that is assigned to a demand, 0 otherwise.
$y_{pf} \in (0,1)$- equal to 1 if FS $f \in F$ on path $p \in P$ is assigned to a demand, 0 otherwise.
$x_{ef} \in (0,1)$- equal to 1 if FS $f \in F$ is occupied in link $e \in E$, 0 otherwise.
The objective of the model is to minimize the total number of FSs used over all fiber links in the network:
$F = \sum x_{ef}$
subject to:

$$\sum_{p\in P_d}\sum_{f\in F} x_{pf} = 1, \forall d \in D \quad (1)$$
$$x_{pf_i} - y_{pf_j} \le 0, \forall d \in D, \forall p \in P_{d,} \forall f_i, f_j \in F, \text{ where } i = 1, \dots, |F| - n_d + 1 \text{ and } j = i, \dots, i + n_d - 1 \quad (2)$$
$$x_{pf_i} = 0, \forall d \in D, \forall p \in P_d, \forall f_i \in F, \text{ where} i = |F| - n_d + 2, \dots, |F| \quad (3)$$
$$\sum_{p\in P_e} y_{pf} - x_{ef} = 0, \forall e \in E, \forall f \in F \quad (4)$$
$$\sum_{p\in P_d}\sum_{f\in F} y_{pf} = n_d, \forall d \in D \quad (5)$$
$$x_{pf}, y_{pf}, x_{ef} \in (0,1), F \in \mathbb{Z}^+, \forall\, p \in P, \forall\, f \in F, \forall e \in E \quad (6)$$

Constraints (1) are related to the path selection from the list of candidate paths and slot selection as the lowest indexed slot assigned to a demand, for each demand *d*. Constraints (2) are related to the spectrum contiguity, what means if slot f_i is selected as the lowest indexed slot for demand *d*, the next slot near to it (consecutive slot) f_j should be also assigned to a demand. FS selection is not allowed if there is no enough space for FS assignment in the frequency spectrum and it is guaranteed by third (3) constraint. Constraints (4) state that FS in each network link could be assigned to at most one demand at the same time so there is no overlapping. Equation (5) ensures that each demand *d* is assigned with the requested number of subcarriers (n_d). At the end, constraints (6) are the variable range constraints that state the problem variables are binary.

4. Numerical results

ILP formulation is applied to the small network with 6 nodes and 9 links topology (shown by Figure 3). The algorithm was implemented using Matlab R2014a (v. 8.3) and Intel Pentium Dual CPU 2.16 GHz 2 GB computer. The number of frequency slots, n_d, required for connection was chosen between 1 and 5. In our simulation we used three different values of *D* to represent load scenarious: 10, 20 and 30 demands (demand pairs). The paths are shortest paths and their number is assumed to be $P_d = 2$.

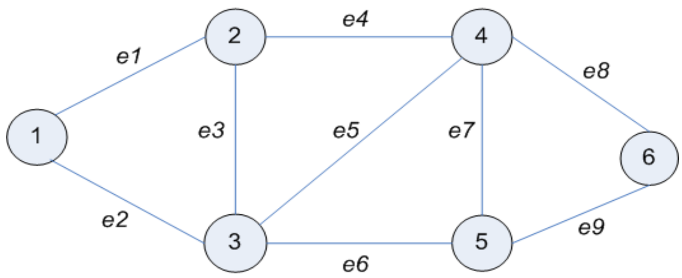


Fig. 3.
Network topology used for simulations
Source: Authors

The results in terms of spectrum usage (total number of FS), the running time and the FS occupancy in network links are presented in Table I and the following histograms. We observe that for all values od *D* the optimal RSA ILP algorithm was able to find solution. The main difficulties of this algorithm are caused due to larger number of demands and FSs thereby resulting in a huge number of constraints and a more running time. So, the optimal solution may be infeasible (scenario for *D*=30, 15 FSs) or a lack of memory could happen.
Figure 4 shows a histogram of the link occupancy where the x-axis represents the network links (from 1 to 9) and a number of slots occupied in each link for all traffic load scenarious are represented in the y-axis. In our case most of the links are almost equally used. Link 4 is the most frequently used. Utilization of less used links (for example link 1) could be increased with a higher number of candidate paths.
A histogram of the FS occupancy in network links (x-axis) is shown in Figure 5. The size of the FS subset (several contiguous slots) is represented on y-axis. The links are grouped as follows: 1-3, 4-6 and 7-9. We wanted to show which FS subset has been most frequently used (FU) as well as the maximum subset size (max). It could be observed that some FSs are released at some links while others are allocated more frequently. This is due to the spectrum contiguity and continuity constraint which in certain cases implies the problem of spectrum dividing into parts which could not be used (isolated), so called fragments. That is why multi-path routing or some techniques of defragmentation should be considered (see Abkenar and Rahbar, 2016). Therefore, our ILP model formulated the routing and spectrum assignment problem in flex-grids optical networks. Because of the running time, the model is not suitable for large networks and some heuristics should be applied.

Table 1
Spectrum usage for all load scenarious

Load- demands (*D*)	FSs in each link	Spectrum usage (total number of FS)	Running time (in seconds)
10	6	32	0.07
10	10	32	0.27
20	10	60	5.10
20	15	60	22.60
30	15	89	633.24
> 30	15	no feasible solution found	

Source: Authors

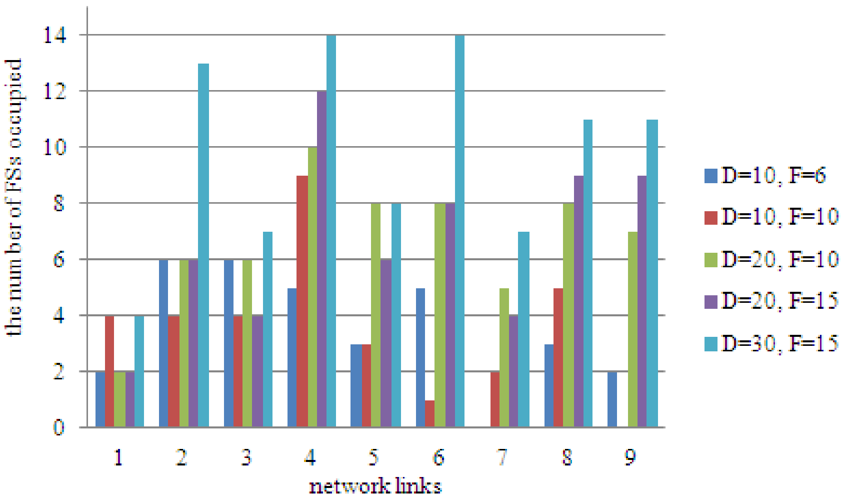


Fig. 4.
Link occupancy in the network
Source: Authors

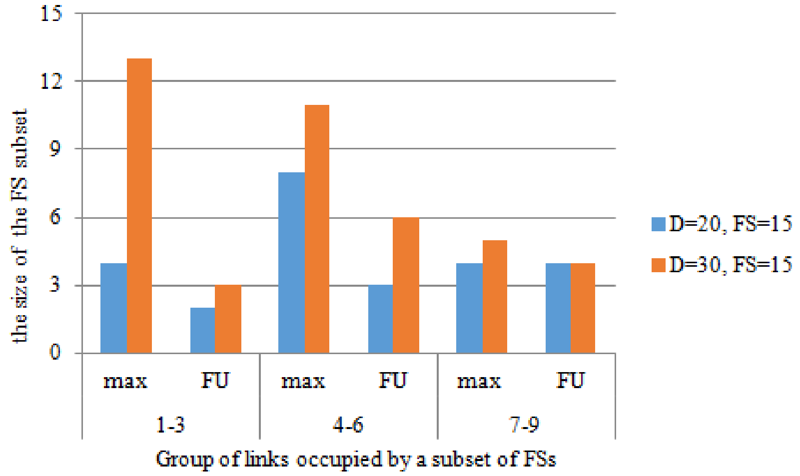


Fig. 5.
FS occupancy in network links (D=20, 30; FS=15)
Source: Authors

4. Concluding remarks

Elastic optical networks represent logical direction in the development of currently deployed networks since the main goal of the next generation optical networks will be the efficient utilization of network resources that could be achieved by flexible bandwidth allocation. It is theirs main difference compared to traditional WDM networks where a large optical spectrum remains unutilized. However, it can not be stated for sure that all networks will become elastic but currently it is the main development trend.

This paper studies the basic concept of flex-grid optical networks and the major problem that should be solved – the problem of routing and spectrum allocation. Our further research directions could be focused on metaheuristics that could solve this problem more efficiently since more complex mesh network topologies, with larger number of FS and traffic demands complicate the ILP formulation and the solution could not be obtained.

Acknowledgements

This research was partially funded by a grant (No. TR 32025) from the Serbian Ministry of Education, Science and Technological Development.

References

Abkenar, F.S.; Rahbar, A.G. 2016. Study and analysis of routing and spectrum allocation (RSA) and routing, modulation and spectrum allocation (RMSA) algorithms in elastic optical networks (EONs), *Optical Switching and Networking*, 23: 5-39.

Chatterjee, B.C.; Sarma, N.; Oki, E. 2015. Routing and spectrum allocation in elastic optical networks: A tutorial, *IEEE Communications Surveys&Tutorials*, 17(3): 1776-1800.

Gerstel, O.; Jinno, M.; Lord, A.; Ben Yoo, S.J. 2012. Elastic optical networking: A new dawn for the optical layer, *IEEE Communications Magazine*, 50(2): 12-20.

ITU-T Study Group 15. 2012. Recommendation G. 694.1: *Spectral grids for WDM applications: DWDM frequency grid*. ITU-T, Geneva, 16 p.

Klinkowski, M.; Careglio, D. 2011. A routing and spectrum assignment problem in optical OFDM networks, In *First European Teletraffc Seminar*. Available from Internet: <http://upcommons.upc.edu/bitstream/handle/2117/13505/ETS2011_v0.7.1.pdf?sequence=1&isAllowed=y>.

Shen, G.; Guo, H.; Bose, S.K. 2015. Survivable elastic optical networks: survey and perspective (invited), *Photonic Network Communications*, July: 1-17.

Socrates-Dantas, J.; Careglio, D.; Perello, J.; Silveira, R.M.; Ruggiero, W.; Sole-Pareta, J. 2014. Challenges and requirements of a control plane for elastic optical networks, *Computer Networks*, 72: 156-171.

Talebi, S.; Alam, F.; Katib, I.; Khamis, M.; Salama, R.; Rouskas, G. 2014. Spectrum management techniques for elastic optical networks: A survey, *Optical Switching and Networking*, 13: 34-48.

Winzer, P.J. 2014. Making spatial multiplexing a reality, *Nature Photonics*, 8(14): 345-348.

Zhang, G.; Leenheer, M.D.; Mukherjee, B. 2012. Optical traffic grooming in OFDM-based elastic optical networks (invited), *IEEE Journal of Optical Communications and Networking*, 4(11): 17-25.

WAREHOUSE PROCESS OPTIMIZATION – CASE STUDY

Ivona Bajor[1], Margareta Rihtarić[2], Dario Babić[3]
[1,2,3] *Faculty of Transport and Traffic Sciences, University of Zagreb, Zagreb, Croatia*

Abstract:
Warehouse processes are, from optimization viewpoint, significant to observe in supply chain regarding process optimization. If the warehouse activities are not well organized, in this important subject of the supply chain it can produce bottlenecks and increase logistics costs. The basic warehouse processes include goods receiving, storage, order picking and shipping.
The paper will analyze problem of defining and measuring warehouse processes, in form of a case study. Aim of the paper is to describe the current state of certain warehouse processes in logistics distribution center at the Croatian market and finally suggest optimization possibilities for the benefit of reducing process time and reducing bottlenecks of this significant part of the supply chain.

Keywords: supply chain, warehouse, processing, process time, case study.

1. Introduction

Processes in the warehouse are of large importance for circulation of goods throughout the supply chain. Warehouse processes refer to loading, unloading, packing, picking, outbound operations and include processes of reverse logistics.
In the past, warehouses were seen mainly as stock-holding points acting as a buffer between manufacturer and consumer. Stock visibility along the supply chain was limited and information flow was very slow, resulting in companies holding more stocks than necessary. In today’s market with often over expensive land, buildings, labor and energy costs, together with the introduction of concepts such as just in time (JIT), efficient consumer response (ECR) and quick response (QR), companies are continuously looking to minimize the amount of stock held and speed up throughput. (Richards, 2011)
The warehouse, which will in form of a case study be described in the paper, is one that acts as a logistics service provider and processes finished goods. Researched warehouse processes consist of receiving operation, positioning, order picking, packing, outbound operations and generally predefined processes for goods in return.
Paper analyzes warehouse processes and its role in the supply chain. It focuses the organization and provides possible suggestions for optimization.
Analysis includes:

- Current state analysis of forwarding processes,
- Processes measurement on predefined sample,
- Comparative analysis of statistical data and optimization proposal.

2. Warehouse operations

Warehouses are the points in the supply chain where product pauses its throughput, it provides additional services and forwards products to the next level of the supply chain. According to mentioned, warehouse requires labor, capital (land and storage with handling equipment) and information systems, all of which are expensive. Warehouses, provide useful services those of significant importance under the current economic scene. (Bartholdi, 2011)
Warehouse management has a mission to effectively process products at the right time, right place, and right quantity without damages or differentiation. (Manzini, 2012)
In today`s supply chain there are many different roles. The warehouse can be operated by raw materials suppliers, manufacturers, retailers, service providers, companies involved in reverse logistics, etc. Warehouses fulfill following roles: (Richards, 2011)

- Raw materials storage,
- Intermediate, postponement, customization or sub-assembly facilities,
- Finished goods storage,
- Consolidation centers and transit warehouses,
- Transshipment or break-bulk centers,
- Cross-dock centers,
- Sortation centers,
- Fulfilment centers,
- Centralized return centers,
- Public sector warehousing.

Basic processes include: receiving, put-away, internal replenishment, order picking, accumulating and sorting, packing, storage, dispatch and shipping. These processes is shown in the Figure 1.

[1] Corresponding author: ivona.bajor@fpz.hr

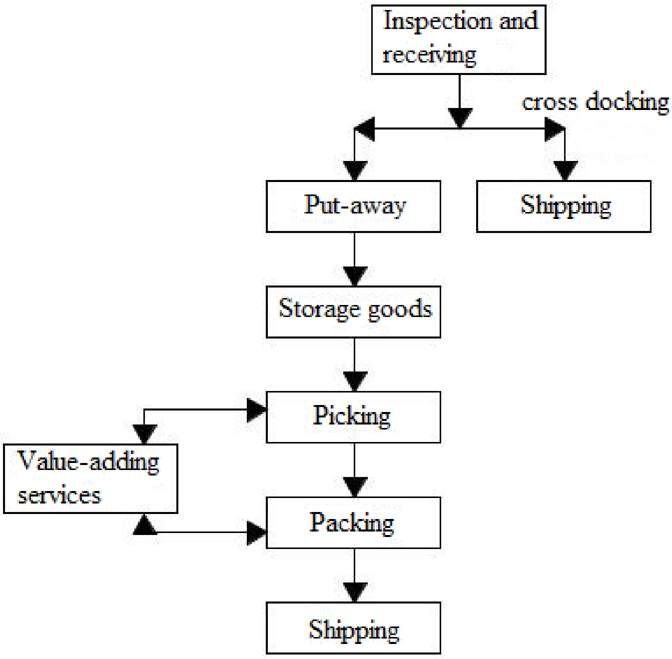


Fig. 1.
Warehouse processes
Source: Created by authors according to (Richards, 2011)

Figure 2 shows each process of warehouse as a percentage of cost, emphasizing the importance of the pick, pack, and dispatch operations. Order picking has majorly been researched as most significant process for optimization and according to mentioned has largest costs. Order picking process forms as much as 55 % of operation costs within any distribution center, compared to shipping, storage and receiving stages, because this process is a labor-intensive activity for traditional manual warehouses.

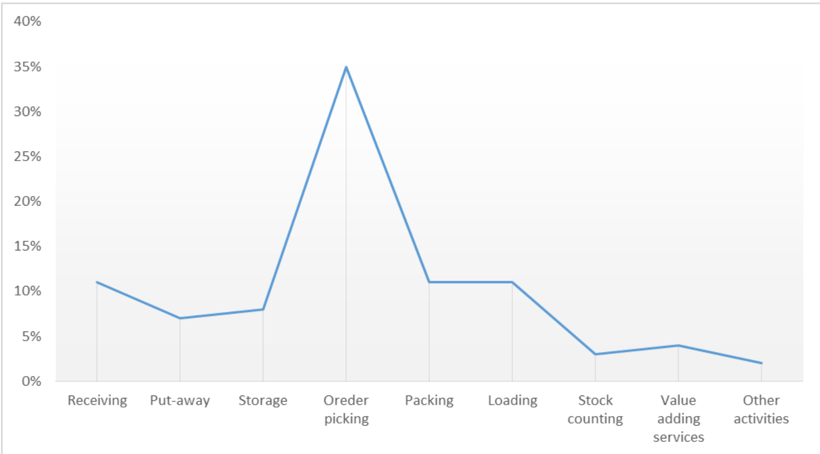


Fig. 2.
Warehouse activities as a percentage of total cost
Source: (Richards, 2011)

2.1. Receiving

The receiving process is one of the most important process and first in line in the warehouse. Because all downstream processes depend upon the accuracy and efficiencies achieved during receiving. Accurate data entry at this phase is critical for preventing costly cascading errors.
The typical procedures of receiving activities consists of four steps: (Warehouse and storage management, 2013)

- Unloading and checking the shipment,
- Unpacking and inspecting the material,
- Completion of the receiving report,
- Delivery of the material.

Ensuring that the correct product has been received in the right quantity and in the right condition at the right time is one of the mainstays of the warehouse operation. However, it is our contention that once goods have arrived at the warehouse it is usually too late to rectify most receiving issues. There are many steps that need to be taken before the actual act of receiving takes place. (Richards, 2011)
In most cases the process of receiving begin with advance notice of the arrival of goods. When goods arrive, unloading begins after document control. Each warehouse must provide the zone for receiving, where the goods are often temporarily positioned. Altogether, process of receiving accounts for only 10% of operating costs in a typical warehouse, but it is supposed to be reduced by use of RFID. (Bartholdi, 2011)

2.2. Put-away

Stock keeping unit (SKU) locations must be determined in advance, whether the positions are predefined or random. There are several storage policies: (Mendes, 2011)

- A predefined storage policy prescribes a particular location for SKU to be stored,
- A random policy leaves the decision to the operator.

One warehouse can also use both of these forms.
Utilizing fixed locations implicates designating a specific location for a particular SKU. A random location is as it states, where the SKU is placed in the most efficient slot available. Fixed positions enable the picker to memorize the actual location and speed up the picking process. However, if there is no stock for that particular product at any one time, the slot remains empty and pallet storage utilization reduces significantly. (Richards, 2011)
Determining the location in advance is important to a large extent directly influencing how quickly and for what cost later it will be retrieved for a customer. When product is put away, the storage location should also be scanned to record where the product has been placed. This information will subsequently be used to construct efficient pick-lists to guide the order-pickers in retrieving the product for customers. (Bartholdi, 2011)
The warehouse manager needs to take into account that items could be stored in groups by similarity. For example, hazardous items need to be stored in an appropriate area. Items of high value will also require special storage conditions, which might mean a lockable cage or the use of a secure carousel. (Richards, 2011)
Many of today’s WMSs allocate product locations in advance and instruct the operator as to where to place the SKUs. In order for this system to work effectively, a great deal of information needs to be programmed into the system. This includes the following: (Richards, 2011)

- Size, weight and height of palletized goods,
- Results of an abc analysis or slotting, where fast-moving goods are placed closest to the dispatch area,
- Current order data,
- Family product groups,
- Actual sales combinations,
- Current status of pick face for each product,
- Size of pallet locations,
- Weight capacity of racking.

The process of put-away can require a larger amount of work because SKU may need to be moved considerable distance to its storage location. Put-away typically accounts for about 15% of warehouse operating expenses. (Frazelle, 1996)

2.3. Order picking

Picking is process which has most work, intensive process, in the warehouse and is also the most error prone, which makes it an ideal workflow for optimizing. Process of the order-picking in the warehouse involves selecting and gathering specified amount of right SKUs in accordance with the order and is composed of lifting, moving, picking, putting, packing and other related works. (Lee, 2015)
The order picking process methods include as following: (Richards, 2011)

- Paper pick lists,
- Pick by label,
- Pick by voice,
- Barcode scanning,
- Radio frequency identification,
- Pick by light/pick to light,
- Put to light,
- Automated picking.

Receipt of a customer order signals the warehouse to perform checks such as verifying that stock is available to ship. The warehouse must produce pick lists to guide the order-picking. Finally, it must produce any necessary shipping documentation and schedule the order-picking and shipping. These activities are typically accomplished by a warehouse management system (WMS), a large software system that coordinates the activities of the warehouse. (Bartholdi, 2011)
Every outbound processes in the warehouse are initiated by receipt of a customer order. This receipt may be thought of as a shopping list. Each entry on the list is referred to as an order-line and typically consists of the item and quantity requested. Pick-lines are instructions to the order-pickers, telling them where (locations of items) and what SKU to pick, including details as quantity and units of measure. (Bartholdi, 2011)
The process of order picking can be manual or automated. In manual order picking, picker gathers SKUs from their locations and then transports them to a packing area. In a case of automated picking, that is automated storage and retrieval systems, system retrieves one or more unit loads and place them to a picking station. After, picker takes products on orders, the remaining items on unit loads are transferred to the storage again. (Lee, 2015)
The WMS may reorganize the list to match the layout and operations of the warehouse for greater efficiency, checks the order against available stock and identifies any shortages. For example, if a customer has ordered 20 of a particular item, the WMS may check to see how the item is packaged and if 15 of the items comprise a carton, the WMS may convert the order-line for 20 items to two pick-lines, one line for one carton and the other for 5 items. In most of warehouses the pick-lines are diverted appropriately and each-picking and carton-picking are separate processes.
Goods are selected from order picking stock in the required quantities and at the required time to meet customer orders. Picking often involves break bulk operations, when goods are received from suppliers in whole pallet quantities, but ordered by customers in less than pallet quantity. (Mohan, 2006)

2.4. Packing

Packing can be labor-intensive due to necessity of handling individual piece. Packing results partly as a complex process according to fact that customers generally prefer to receive all the parts of their order in as few containers as possible because this reduces shipping and handling charges. Otherwise partial shipments must be staged, waiting completion before packing, or else partial orders must be packaged and sent. (Bartholdi, 2011)
The worker during packing checks each product, in order to determine the accuracy. After the packing process, the transport packaging is directed to shipping.

2.5. Shipping

The shipping process generally handles larger units. The shipping process is the last process amongst warehouse processes. After the packing process and preparing cargo for shipping, administration, cargo is positioned into the transportation vehicles and transported to the destination. (Bartholdi, 2011)

3. Case study of warehouse operations in LDC at the Croatian market

The research has been made at location of a logistics service provider at the Croatian market. Croatian service provider is a significant company that offers basic logistics service and some value added services. Service provider`s warehouse has surface of 8555 m^2. The warehouse space is physically divided into three parts, the zone of receipt, dispatch and zone for reverse logistics processes. The workers are working in two shifts: in the morning 8 a.m. to 4 p.m. (12 warehouse workers); and in the afternoon 12 to 8 p.m. (17 warehouse workers).
The processes which service provider offers in warehouse are:

- Receiving,
- Put-away,
- Order picking,
- Packing,
- Checking,
- Shipping,
- Reverse logistics,
- Value adding services.

The process of receiving begins with the announcement of the arrival of goods. At arrival of the truck, the warehouse workers perform control of the documents and start with unloading the goods from the trucks. The goods are in cardboard boxes. During unloading, warehouse workers are grouping cardboard boxes on the pallet according to type criteria. Once the goods are on pallets the workers begin the process of labeling. Each box is opened and declarations, instructions and warranty are put into the box. Once the goods are officially declared, pallets are ready for storage on the first available location. The goods are mostly stored so that the goods whit high turnover are located at the first location (pick location), and if there are goods of the same type to another location. The goods with low turnover and seasonal goods are positioned at several locations on the shelves. Once the goods are stored the process of picking can begin. According to customer orders, order picking process has two channel:

- I channel: the ordering goes from the final customer – the goods after picking process are directed to the packing location for further processing;
- II channel: the ordering goes from wholesale - the goods are directed to control location and further processing.

When the goods of the first channel enter packaging zone, workers according to customer orders pack products in cardboard boxes, grouping orders and placing them on a pallet according to the type of the carrier. In the end pallets are taken to the dispatch ramp. Goods from second channel are directed to zone for control where workers check items and ship final packaging to the dispatch ramp.
In the end products are ready for shipment positioned at the dispatch ramp for shipment. Once the products are shipped and arrive to destination, can be returned if the consumers is not satisfied or the product is damaged. Warehouse processes are shown with Figure 3.

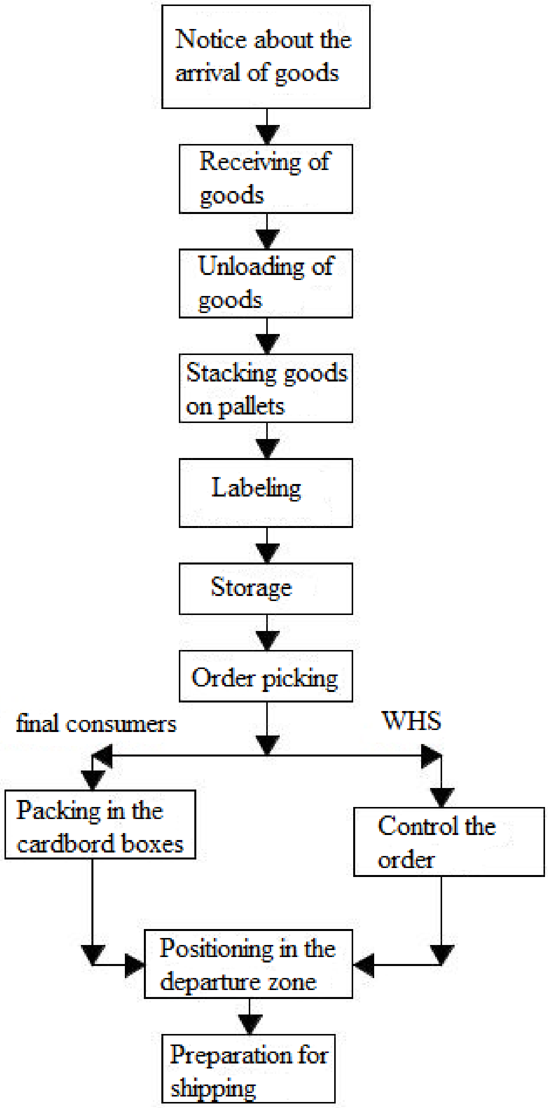


Fig. 3.
Croatian logistics service provider warehouse processes
Source: Created by authors

The analysis was done in the following way:
- Analysis of the current situation in the process, including specification regarding warehouse space,
- Bottlenecks analysis,
- Proposing solutions regarding bottlenecks,
- Analysis after the implementation.

For the purposes of conducted research, measurements of the warehouse process were conducted. Table 1 implicates the time duration of receipt, labeling, storage, order picking and packing.

Table 1
The average time of the processes

Time of receipt (per pallet) [s]	Time of labeling (the cardboard box) [s]	Time of storage (per pallet) [s]	Time of order picking (by order) [s]	Time of packing (per account) [s]
0:10:05	0:02:13	0:02:37	0:09:27	0:06:25

Source: Created by authors

The next chart shows the average time per activity for the receipt, from which is evident that most time is required for positioning the vehicle on the ramp which is not connected with the activities within the warehouse. While activity of unloading cardboard boxes on a pallet on average takes more than two minutes per pallet, and the average number cardboard boxes in a single means of transport is about 1 000, or about 65 pallets. If we consider that for the formation of a pallet two minutes are needed, the average time of unloading takes two and a half hours. It often happens that during unloading the pallets are missing, so the cardboard boxes first land on the floor of the warehouse, and later again on the pallet.

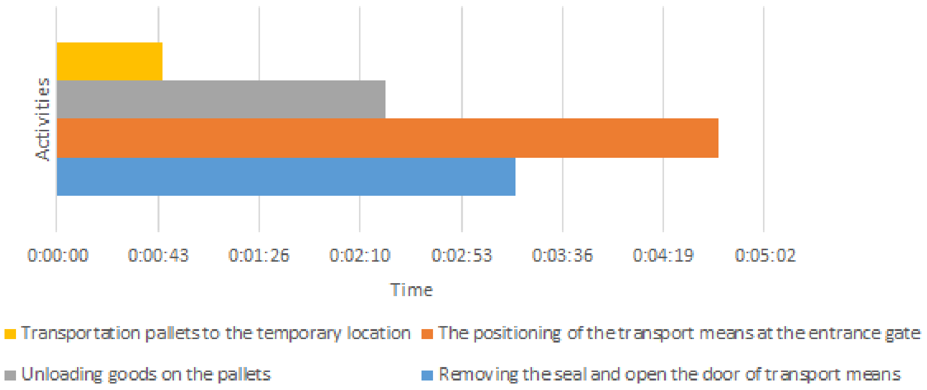


Fig. 4.
Receipt of goods
Source: Created by authors

The graph below shows the process of labeling. During the research it was concluded that significant problem in the labeling process is that there is no pre-prepared declarations for complete product arsortiment. Since the arrival of the truck is advised two days earlier, the necessary declaration could be prepared the day before. From the next graph we can see how type of goods influences the time of labeling. Considering the type of labeling products, the products are divided into three categories:

- I product category – includes instructions,
- II product category – includes instructions and declaration,
- III product category – includes declaration on each product in the packing.

The graph implicates that most time required is for products of third category, the procedure is the easiest because it's just pasting the labels, but the package has multiple products so the process of labeling takes longer.

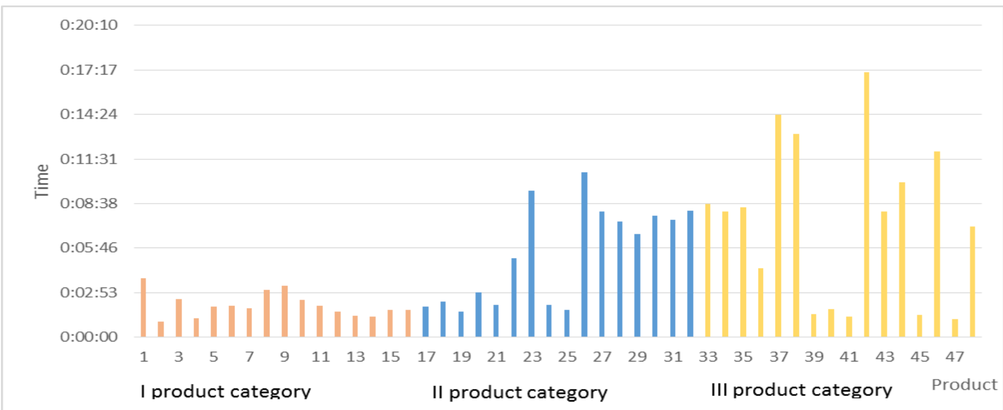


Fig. 5.
Process of labeling
Source: Created by authors

The graph below implicates the order picking process activities. It can be seen that the most time consuming is activity of collecting the product from the shelf. This is due to the fact the products are not arranged on the shelves according to ABC categorization, but are in randomly positioned in the warehouse.

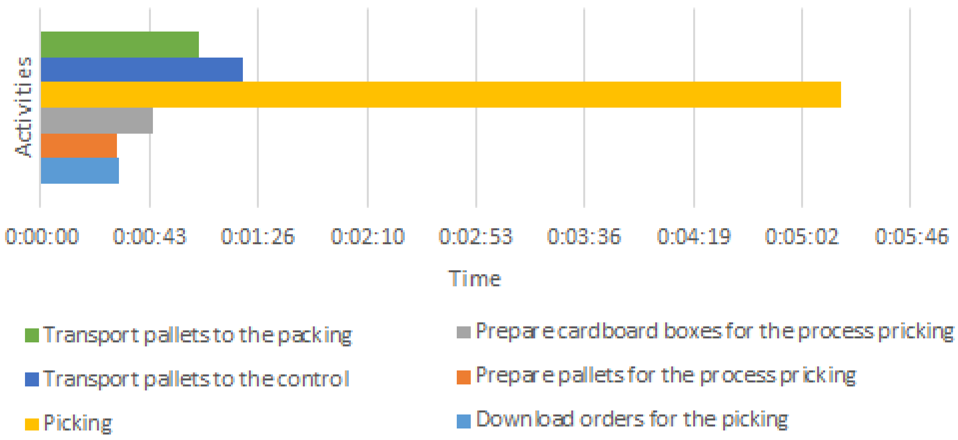


Fig. 6.
Process order picking
Source: Created by authors

Although the warehouse processes are well-organized, certain segments were found, which could be improved. From the overall analysis, it is concluded that the company has some room for optimization, which will be detailed and explained in the next section.

4. Proposal for warehouse operations improvement

The proposal to improve logistics activities within the warehouse is made on the basis of the aforementioned analysis. With the improvements it is possible to some extent to shorten the time of existing processes and achieve higher levels of efficiency.
Analysis of the warehouse processes indicates more optimization possibilities, and some of these features are:

- To reduce the preparation work it was suggested to organize the goods by packaging (pallets, cardboard boxes),
- Sorting the cardboard boxes for packaging by size and better organization for ordering,
- Reducing the necessary time for putting the receipts in the envelopes and picking of the products according to the receipt for the packing process,
- Detailed procedure of activities to increase the transparency of worker obligations.

Based on conducted study and regarding the warehouse processes, it is possible to propose certain directions for further optimization. Some of the suggestions for optimizing relate to the observed processes:

- **the receipt of goods**
  During the research it was noted that the goods are in receipt often received after 8 am as a pre-set schedule, and that for this process the company hired a number of students (temporary workers). With a view to better planning the necessary resources should consider accurate notice of arrival of the conveyance by the carrier. This information could result in a cost reduction. In addition, there is the possibility of employment for one worker. This worker can control the course of the unloading process and thus reduce errors that occur while temporary workers are obtaining activities and to reduce necessary time period. In addition to this, while conducting research, the lack of pallets has been noted, which are necessary for the temporary storage of goods during unloading. This deficiency causes the double handling of goods, and unnecessary waste of time in the process of receiving and resources used. To solve this problem, it is proposed dedicating zone for empty pallets and to provide a sufficient number of pallets which are necessary for reception of the goods.
- **process of labeling**
  When analyzing the process of labeling, temporary workers have to take each cardboard box of the pallet then open it, put the instructions and declarations, close and then put again on a pallet after labeling. Such a procedure results with double manipulation. If the preparation of instructions and declarations is made in advance, there is no loss of time in the process. During the measurement it was noticed that almost always declaration and the instructions are prepared during the execution of the process, which prolongs the process. Since the arrival of goods is known in advance, the preparation of the necessary instructions and declarations for all goods which are coming in the transport vehicle should be arranged before. Because the students are doing the process of labeling, there should be an employee to control them.

- **Order picking and packing**
  During the research it was noticed that warehouse workers (pickers) spend some time searching for pallets for orders picking, which increases the process time. Empty pallets are located at different locations in the warehouse or even at storage locations within the rack.
  One proposition would be to organize empty pallet zone, in the order that the workers could easily reach them. In addition, it was noted that a worker has to go often to the higher level racks to pick goods. For this operation he needs electric forklift, which worker must wait for the release, but it also increases the time. For this problem better organization of manipulation means is proposed.
  The analysis implicated that workers in the packing zone do not have a sufficient amount of transport packaging in form of card boxes.
  This results with creating packaging of needed dimensions, which requires a certain commitment of workers and extending the time of packaging process. In order to avoid this, it is proposed to predefine dimensions and quantities of cardboard packaging and plan inventories of those according to available data.

5. Conclusion

The warehouse processes are significant to optimize in the supply chain. Every process, from receiving until shipping, is vital since it causes certain costs. Order picking process is the one that accounts for the major percentage of warehouse operating costs and is most time consuming for warehouse workers.
The logistics service provider at Croatian market is well organized but analysis implicates certain possibilities for optimization within receiving of goods and order picking process.
The analysis of the logistics processes was done in the segment of storage at the Croatian company, providing logistics services. During the research it was noticed that all the actions in the given segment were well organized and that there are only minor disadvantages, which can be bettered with reorganization of the preparatory work and some activity reorganization.
During the analysis there have been some problems noted, related to following cases:

- Lack of pallets during unloading goods from the means of transport and order picking process,
- Lack of cardboard packaging in the packing zone,
- Lack of organization while preparing declarations and instructions for the process of labeling.

For all the problems proposition is made for possible improvements that could:

- Uniform work processes in the warehouse,
- Reduce the warehouse costs,
- Improve the quality of services.

Continuous control and process measurement can provide optimal processing and it is highly recommended for subjects of the supply chain. Transparency of the processes assures its visibility and provides easier control of resources used.

References

Bartholdi, J.J.; Hackman, S.T. 2011. *Warehouse and Distribution Science*, The Supply Chain and Logistics Institute, School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, U.S.A.
Frazelle, E.H. 1996. *World-Class Warehousing*, Logistics Resources International, Atlanta, U.S.A.
Lee, J.A.; Chang, Y.S.; Shim, H.; Cho, S. 2015. A study on the picking process time, *Procedia Manufacturing*, 3: 731-738
Manzini, R. 2012. *Warehousing in the Global Supply Chain*, Springer, London, UK.
Mendes, P. 2011. *Demand Driven Supply Chain: A Structured and Practical Roadmap to Increase Profitability*, Springer Berlin Heidelberg, Berlin, Germany.
Mohan, V.E. 2006. *Warehousing and inventory management*. Course material, CII Institute of Logistics, Chennai, India.
Richards, G. 2011. *Warehouse Management: A complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse*, KPL, Philadelphia, U.S.A.
Warehouse and storage management. 2013. Available from Internet: <http://warehouse-and-storage-management.blogspot.hr/2013/03/receiving-procedure.html>.

SESSION 18: TRANSPORT SAFETY AND SECURITY ANALYSIS

HOW DO WE PERCEIVE TRAFFIC RISK?

Jiří Ambros[1], Lucie Viktorová[2], Richard Turek[3], Matúš Šucha[4]
[1,3] *CDV – Transport Research Centre, Department of road safety evaluations and strategies, Líšeňská 33a, 636 00 Brno, Czech Republic*
[2,4] *Palacký University Olomouc, Faculty of Arts, Department of Psychology, Křížkovského 10, 771 80 Olomouc, Czech Republic*

Abstract: Traffic risk perception has been defined as a subjective interpretation of the risk involved in traffic situations; this concept is important for road safety, since it may predict how road users behave in traffic. In addition risk perception is often reflected in safety assessments: both from experts (during road safety inspections or investigations) and lay persons (in road user safety complaints). Subjective risk perception is also valuable in cases when other safety data are missing, for example due to underreporting or newly-built infrastructure; hence it is of interest to study the factors which determine how we perceive traffic risk.
In this respect an on-line test was prepared, consisting of general questionnaire (gender, age, driving experience), risk perception assessment (rating level of risk in video clips of traffic situations), personality questionnaire, and Driver Behaviour Questionnaire. With objective of studying the links between subjective risk assessment and personality traits, as well as differences across several dimensions (such as male vs female drivers, less/more experienced drivers, drivers vs other road users, or lay persons vs safety experts), the test was used with 144 respondents, including students and adults, certified road safety auditors or Traffic Police officers. In total 9 hypotheses were formulated and statistically tested: some of the identified relationships provided expected results, consistent with previous studies: for example high risk perception of females compared to males or lack of differences between students (non-professionals) and experts (professionals); other findings were less expected, for example lack of relationships of risk perceptions to age and experience. Nevertheless in order to reduce potential consequences of subjective assessments, based on risk perception, the identified differences should be considered in future road safety auditors' or traffic conflict observers' training procedures.

Keywords: road safety, traffic risk, risk perception, driver behaviour.

1. Introduction

It is recognized that majority of road traffic accidents may be attributed to human error (Treat et al., 1979; Hendricks et al., 2001; Andres et al., 2012). In order to propose appropriate safety countermeasures, it is thus necessary to investigate road users' characteristics and behaviour. One of determinants is traffic risk perception (also referred to as hazard perception or situation awareness), i.e. a subjective interpretation of the risk involved in traffic situations (Deery, 1999). It is also closely related to subjective safety, which refers to anxiety regarding being unsafe in traffic for oneself and/or others (Vlakveld et al., 2008). Since road users modify their behaviour according to the risk they perceive, the concept is fundamental for traffic safety – knowing risk perception may enable prediction of safety. Past studies found links of risk perception to safety in various traffic environments (e.g. Watts and Quimby, 1980; Kanellaidis and Dimitropoulos, 1994; Kowtanapanich et al., 2006; Lipovac et al., 2016). Numerous studies also described risk perception as a skill that is highly correlated with traffic crashes: experienced drivers perceive potential risk situations better and more quickly than novice drivers, while drivers who can detect hazards faster are less involved in traffic crashes than those who detect hazards slower. In contrast, inexperienced drivers with less developed risk perception skills, were found more likely to be involved in a crash (Peltz and Krupat, 1974; Armsby et al., 1989; McKenna and Crick, 1997).
Several factors were found associated to risk perception and subjective safety, including:

- Traffic features, such as road geometry, speed, traffic volume or traffic separation (Żakowska, 1995; Cho et al., 2009; Sørensen and Mosslemi, 2009),
- Biological, psychometric, cultural and societal characteristics (af Wåhlberg, 2001; Nordfjærn et al., 2011; Lim et al., 2013).

In addition, subjective safety in traffic can lead to road users limiting their mobility and social activities, which is one of the reasons it warrants policy-related attention; understanding risk perception is also important for traffic enforcement and traffic education, or for design of appropriate safety campaigns. Another interesting application is local safety assessment – i.e. using perceived (or *subjective*) risk in order to determine safety level of specific location (e.g. an intersection) or the events, which take place on such location. Traditionally *objective* safety measures have been used for this purpose, based on frequency of accumulated accidents; however accident-based measures enable reactive (retrospective) approach only. In contrast, alternative (proactive) measures, which are valuable in cases of accident non-existence, rarity or underreporting, are so called safety performance indicators or surrogate safety measures, e.g. traffic conflicts (Ambros et al., 2014). The proactive measures, utilizing principles of risk perception, may complement process of road safety inspections (Ambros et al., 2016), which are mostly based on expert judgment. These assessments are usually done off-road (outside-of-vehicle) as opposed to typical hazard perception studies being conducted from the driver perspective (on-road or in driving simulators).

[1] Corresponding author: jiri.ambros@cdv.cz

Given the interesting concept of traffic risk and its applications, it is worth investigating the factors which determine how we perceive risk. With this focus we prepared an on-line test, consisting of general questionnaire (gender, age, driving experience), risk perception assessment (rating level of risk in video clips of traffic situations), personality questionnaire, and Driver Behaviour Questionnaire. We used the test with several groups of students and adults, including certified road safety auditors or Traffic Police officers. The objective was to study the link between subjective risk assessment and personality traits, as well as differences across several dimensions, such as male vs female drivers, less/more experienced drivers, drivers vs other road users (cyclists, pedestrians), or lay persons vs traffic safety experts. The paper presents data and methods, hypotheses testing and results, followed by discussion, summary and conclusions with focus on practical implications.

2. Method

2.1. Test

An on-line test was prepared (http://riziko.cdvinfo.cz/), consisting of four parts:

1. General questionnaire (gender, age, driving experience, etc.)
2. Risk perception assessment (rating level of risk in video clips of traffic situations)
3. Personality questionnaire TVP (129 items)
4. Driver Behaviour Questionnaire (50 items)

The general questionnaire aimed at collecting basic demographic information in 30 items (gender, age, educational and marital status, occupation – including type of school and year of study in case of students, population of the city of residence, etc.) as well as information pertaining to driver experience (type and year of obtaining a driving licence, average monthly/yearly/accumulated mileage, driving offences and accidents, etc.). A five-point Likert scale was used for self-assessment of the respondents' driving skills (1 – excellent, …, 5 – very poor) and the participants were also asked to identify themselves with one group of the road users: drivers, cyclists or pedestrians.
Following the initial set of questions, a risk perception assessment was carried out using 35 video clips, i.e. short (approx. 10 seconds) records of traffic situations, displaying various situations in mostly urban environments. In terms of Czech traffic conflict technique (Ambros et al., 2014) severity grades, the interactions ranged from "none" to "severe". They displayed different interaction types between vehicles (crossing, turning, overtaking, rear-end) or between vehicles and pedestrians. The application text instructions informed the respondents that on a picture (prior to running the video) they can see the location of a traffic interaction. After running and watching the video (with one possible repetition) they were instructed to assess the perceived severity (not based on traffic rules compliance or non-compliance) on a drop-down menu (Fig. 1) using four-point Likert scale: 0 (none), 1 (slight), 2 (medium) or 3 (severe).

Fig. 1.
Interface of video clips in the on-line application, with perceived risk severity assessment on the right

The second half of the test comprised two questionnaires. First of them was the Personality questionnaire TVP ("Test zur Erfassung verkehrsrelevanter Persönlichkeitsmerkmale", Spicher and Hänsgen, 2003; Czech version by Černochová and Rudá, 2016), which is used for personality diagnostics within the scope of traffic psychology and consists of 129 four-point Likert-type items (1 – strongly disagree, …, 4 – strongly agree). There are 13 scales in total, with 7 to 12 items loading on each scale. The scales follow the Five Factor Model of personality (Neuroticism, Extraversion, Openness to experience, Agreeableness, Conscientiousness), with each factor being measured as "traffic-specific" and

"generic" (10 scales in total). Besides the five factors, "disparagement" (generic and traffic-specific) as a measure of socially desirable answers is assessed, and a reactance scale is added. The higher the score on each scale, the more noticeable the trait is for the participant.
The second was the Manchester driver behaviour questionnaire (DBQ, Reason et al., 1990; Czech version by Šucha et al., 2014), used to survey aberrant driving behaviour. It consists of 3 factors (Dangerous Violations, Dangerous Errors, Straying and Loss of Orientation) and 50 items in total. A six-point rating scale is used to measure the frequency of a particular behaviour (0 – never, …, 5 – nearly all the time): the higher the score on each factor, the more often the participant displays the aberrant driving behaviour.

2.2. Respondents

The selection of respondents followed the idea of sampling the driver population (i.e. only the holders of a driving licence) across age groups; additional idea was to use university students from several different backgrounds. Respondents were asked mostly through e-mail to participate in a survey, with no financial incentives. In the e-mail they were directed to the on-line application website, where they were to register, sign in and fill in all four mentioned parts of the test.
Following groups were targeted:

1. University students
    a. psychology students at Palacký University Olomouc (Czech abbreviation "UPOL")
    b. students of College of Logistics in Přerov ("VŠLG")
    c. transportation students of Czech Technical University in Prague ("ČVUT")
2. Traffic police officers, attending courses at Police College of the Ministry of the Interior in Prague ("VPŠ")
3. Road safety auditors, certified by the Ministry of Transport
4. Adults (i.e. non-students)

Participation of university students was arranged within their current classes; other groups participated in their free time. In total 263 respondents filled in the test; 144 (55%) of them, who completed all 4 parts, were used for the analysis. Due to small sub-samples, auditors and Traffic Police officers (VPŠ) were combined into Experts; Adults were renamed to Seniors in order to be distinguished from *adult* Experts. Selected characteristics of the subgroups are summarized in Table 1 in terms of their frequencies (counts and percents), age (minimum, maximum, mean, standard deviation) and gender structure.

Table 1
Selected descriptive characteristics of the respondents' sub-samples

	Frequency		**Age**				**Gender**	
	N	**%**	**Min.**	**Max.**	**Mean**	***SD***	**Male**	**Female**
VŠLG	55	38.2	20	25	21.8	1.12	32	23
ČVUT	24	16.7	20	32	22.4	2.18	17	7
UPOL	19	13.2	19	38	23.5	4.13	3	16
Seniors	22	15.3	30	79	53.1	13.71	16	6
Experts	24	16.7	28	67	41.3	9.94	20	4
Total	**144**	**100.0**	**19**	**79**	**30.2**	**13.83**	**88**	**56**

Respondents were mostly single (69%) or married (26%). In total, 65% and 35% identified themselves as drivers and "other users" (pedestrians or cyclists), respectively. They mostly used their traffic mode in order to get to their work or study location (40%), or short trips for shopping, socializing, sport, etc. (38%). They reported average monthly mileage 1080 km (range 0 – 10,000; SD = 1507.46). Škoda was reported as a typical vehicle brand (41%). Roughly one third confessed to having been fined for a traffic offence, such as speeding or wrong parking. Six respondents (4%) reported having their driving licenses withdrawn; seven respondents (5%) obtained penalty points. In total 22% caused an accident and 26% participated in accident, both mostly with slight injuries. Due to the differences in further demographic and driver experience-related characteristics, the 5 groups presented in Table 1 were retained in the study.

2.3. Data analysis and hypotheses testing

Individual respondents' data, which were obtained from on-line application, were treated as:

– Independent variables (demographic data and variables related to driver experience)
– Dependent variables (average of perceived risk from 35 video clips, 13 TVP scores and 3 DBQ factors)

We formulated following 9 hypotheses:

– H1: The average risk perception of traffic situations is lower for males than for females.
– H2: The average risk perception of traffic situations is lower for road users, who identify themselves as drivers, than for those identifying themselves as "other users".

- H3a: There is a positive association between perceived risk and age (the older the respondents, the higher their average risk perception).
- H3b: There is a negative association between perceived risk and years of holding a driving licence (the more years, the lower the average risk perception).
- H4a: There is a negative association between perceived risk and average monthly mileage (the higher the monthly mileage, the lower the average risk perception).
- H4b: There is a negative association between perceived risk and total accumulated mileage (the higher the total mileage, the lower the average risk perception).
- H5: There is a negative association between perceived risk and self-assessment of driving skills (the better the grade for the driving skills, the higher the average risk perception).
- H6: There is a negative association between perceived risk and population of city of residence (the higher the population, the lower the average risk perception).
- H7: There is a difference in average risk perception between the student groups UPOL, VŠLG, ČVUT, the expert group and the group of seniors.

Hypotheses were tested in IBM SPSS according to the following steps:

1. For each hypothesis containing an association measure, the level of each variable was determined based on the scale used (e.g., ordinal scale for self-assessment of driving skills, continual scales for age, mileages, years of holding a driving license and average risk perception).
2. For each hypothesis containing a group comparison, the normality assumption of the dependent variable was tested for each group using Shapiro-Wilk test with $\alpha = 0.05$.
3. For each hypothesis containing a group comparison, the homogeneity of variances assumption was tested using Levene's test with $\alpha = 0.05$.
4. Based on the results of the assumption testing, following methods were chosen to test the individual hypotheses:
   a. for H1 and H2, an independent-samples t-test (one-tailed, $\alpha = 0.05$) and Cohen's d as a measure of effect size;
   b. for H3a, H3b, H4a, H4b and H6, Pearson correlation coefficient (one-tailed, $\alpha = 0.05$);
   c. for H5, Spearman correlation coefficient (one-tailed, $\alpha = 0.05$);
   d. for H7, one-way analysis of variance ($\alpha = 0.05$).

Besides the hypotheses, between-group differences (UPOL, VŠLG, ČVUT, experts, and seniors) were also tested for TVP scales and DBQ factors. Shapiro-Wilk test was firstly used to investigate normality assumption of all dependent variables for each group. Normality held ($p > 0.05$) for most TVP scores, with exception of generic extraversion for VŠLG students ($p = 0.037$), traffic-specific extraversion for UPOL students ($p = 0.004$), traffic-specific agreeableness for UPOL students ($p < 0.001$) and reactance scale for all student groups ($p < 0.05$). Each DBQ factor showed non-normal distribution of the scores for at least 2 of the groups ($p < 0.01$), which could be expected due to the nature of the variables (aberrant behaviour). Differences between groups in terms of all TVP scores, with the exception of reactance scale, were then analysed using one-way analysis of variance ($\alpha = 0.05$) and post-hoc tests with Bonferroni correction where necessary. Kruskal-Wallis test was used to test for group differences for the reactance scale and DBQ factors ($\alpha = 0.05$; post-hoc tests with adjusted p-value were also carried out where necessary).

3. Results

Overall differences between groups in the TVP scale scores are summarized in Table 2.

Table 2
Differences between groups in generic (g) and traffic-specific (t) TVP scales, using one-way analysis of variance (ANOVA, df1 = 4, df2 = 139)

	VŠLG		ČVUT		UPOL		Seniors		Experts		ANOVA	
	Mean	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	***F***	**Sig.**
Extraversion-g	27.45	5.76	25.33	4.53	25.63	5.73	26.59	4.72	25.83	6.47	0.874	0.482
Extraversion-t	27.06	6.69	23.33	5.95	19.90	5.67	21.68	4.2	20.50	5.17	8.981	< 0.001
Neuroticism-g	28.73	4.66	29.96	4.85	31.44	4.82	25.82	5.27	25.88	4.90	5.776	< 0.001
Neuroticism-t	20.95	4.99	21.50	3.97	25.11	4.82	19.50	5.27	18.92	5.60	5.420	< 0.001
Conscientiousness-g	36.44	4.68	38.25	4.56	37.21	4.69	36.64	4.17	38.13	4.10	1.061	0.378
Conscientiousness-t	25.98	3.87	26.50	3.66	25.84	3.93	28.18	3.57	27.54	3.85	1.879	0.117
Openness-g	24.42	5.30	27.17	3.81	29.26	5.53	30.41	3.69	27.75	3.83	8.884	< 0.001
Openness-t	21.47	4.93	20.92	5.66	15.58	4.51	18.91	4.30	19.80	5.44	5.587	< 0.001
Agreeableness-g	24.86	3.70	24.92	4.40	27.68	1.70	27.96	4.19	27.88	3.79	5.665	< 0.001
Agreeableness-t	15.69	3.44	17.92	3.51	20.84	2.75	18.41	3.32	20.33	2.44	14.140	< 0.001
Disparagement-g	31.58	3.94	30.42	3.15	30.68	3.54	31.32	4.24	30.73	3.70	0.536	0.709

Disparagement-t	24.35	4.44	23.96	5.36	26.42	5.00	24.90	5.34	25.83	4.80	1.207	0.311

Post-hoc tests with Bonferroni correction were carried out in case of significant ANOVA results. Based on these, a difference between VŠLG students and all other groups except for ČVUT students was found in traffic-specific extraversion (p < 0.01 for each VŠLG-group comparison, except ČVUT, p = 0.104). In generic neuroticism, a difference exists between ČVUT students and seniors as well as experts (p < 0.05 each), and between UPOL students and seniors as well as experts (p < 0.01 each). In traffic-specific neuroticism, a difference was found between UPOL students and VŠLG students (p < 0.05), UPOL students and seniors and experts (p < 0.01 each). Further, a difference between VŠLG students and all other groups except for ČVUT students was found in generic openness (p < 0.05 for each VŠLG-group comparison, except ČVUT, p = 0.146). In traffic-specific openness, a difference exists between UPOL students and VŠLG and ČVUT students (p < 0.01 each). In generic agreeableness, a difference was found between VŠLG students and seniors as well as experts (p < 0.05 each), and a possible difference might exist between VŠLG and UPOL students (p = 0.051). Finally, a difference between VŠLG students and all other groups except for ČVUT students (p = 0.052) was found in traffic-specific agreeableness (p < 0.01 each), and there was a difference between ČVUT and UPOL students in this trait as well (p = 0.035).
Group differences in the reactance scale were examined using Kruskal-Wallis test (K-W = 41.220; df = 4; p < 0.001), with a difference found between VŠLG and UPOL students (p < 0.001), ČVUT students (p = 0.012) as well as experts (p < 0.001). Using Kruskal-Wallis test, no group differences were found in DBQ factor 2 (Dangerous Errors; K-W = 5.197; df = 4; p = 0.268) or factor 3 (Straying and Loss of Orientation; K-W = 1.592; df = 4; p = 0.810). The only difference between the groups was found in factor 1 (Dangerous Violations; K-W = 10.881; df = 4; p = 0.028), probably due to the difference between VŠLG and UPOL students (unadjusted p = 0.018) as well as experts (unadjusted p = 0.009); the adjusted p-values were, however, not significant in the post-hoc tests (p = 0.178 and p = 0.089 respectively). In the following paragraphs, individual hypothesis tests are reported.

3.1. H1: The average risk perception of traffic situations is lower for males than for females

Descriptive characteristics are reported in Table 3. Normality assumption of average risk perception was retained (Shapiro-Wilk test, p > 0.05 for both groups), as well as the assumption of homogeneity of variances of both groups (Levene's test, F = 0.553, p = 0.458). Using the independent samples t-test, at the significance level of 0.05, a difference was found between males and females in their average risk perception (one-tailed t_{142} = –2.766, p = 0.003). On average, females perceive the risk of traffic situations as higher than males. Therefore, hypothesis H1 is accepted. In terms of practical significance (statistical power), the effect size is medium (Cohen's d = 0.473).

Table 3
Descriptive characteristics for testing of hypothesis H1, using Shapiro-Wilk (S-W) test

	N	**Mean**	*SD*	*SE*	**S-W test**	**Sig.**
Males	88	1.59	0.46	0.05	0.991	0.787
Females	56	1.81	0.47	0.06	0.984	0.647

3.2. H2: The average risk perception of traffic situations is lower for road users, who identify themselves as drivers, than for those identifying themselves as "other users"

Descriptive characteristics are reported in Table 4. Normality assumption of average risk perception was retained (Shapiro-Wilk test, p > 0.05 for both groups), as well as the assumption of homogeneity of variances of both groups (Levene's test, F = 0.938, p = 0.334). Using the independent samples t-test, at the significance level of 0.05, no difference was found between drivers and "other users" in their average risk perception (one-tailed t_{141} = –0.053, p = 0.479; Cohen's d = 0.008). Therefore, hypothesis H2 is rejected.

Table 4
Descriptive characteristics for testing of hypothesis H2, using Shapiro-Wilk (S-W) test

	N	**Mean**	*SD*	*SE*	**S-W test**	**Sig.**
Other users (pedestrians/cyclists)	50	1.67	0.42	0.06	0.978	0.457
Drivers	93	1.68	0.51	0.05	0.989	0.600

3.3. H3a: There is a positive association between perceived risk and age (the older the respondents, the higher their average risk perception)

Based on Pearson correlation coefficient, no association between perceived risk and age was found at α = 0.05 level (one-tailed r_{144} = –0.033, p = 0.348). Therefore, hypothesis H3a is rejected.

3.4. H3b: There is a negative association between perceived risk and years of holding a driving licence (the more years, the lower the average risk perception)

Based on Pearson correlation coefficient, no association between perceived risk and years of holding a driving licence was found at $\alpha = 0.05$ level (one-tailed $r_{144} = 0.003$, $p = 0.486$). Therefore, hypothesis H3b is rejected.

3.5. H4a: There is a negative association between perceived risk and average monthly mileage (the higher the monthly mileage, the lower the average risk perception)

Graphs in Fig. 2 display the average perceived risk plotted against average monthly mileage (in kilometres). Based on Pearson correlation coefficient, initially, no significant association between perceived risk and average monthly mileage was found at $\alpha = 0.05$ level (one-tailed $r_{144} = -0.120$, $p = 0.076$). Upon closer inspection, there are 4 outliers in the sample (full dots in the left graph) – the drivers who reported driving 5800 km per month or more. After discarding these respondents, the correlation increases and becomes statistically significant (one-tailed $r_{140} = -0.157$, $p = 0.032$; restricting the hypothesis to drivers with an average monthly mileage < 5800 km). However, the association is still very weak (R^2 close to zero in both cases) and there are no further reasons for discarding the outliers (except that they have unusually high average monthly mileage in comparison with the rest of the sample). We therefore conclude, in compliance with the initial results, that there is no significant association between perceived risk and average monthly mileage and reject the hypothesis H4a.

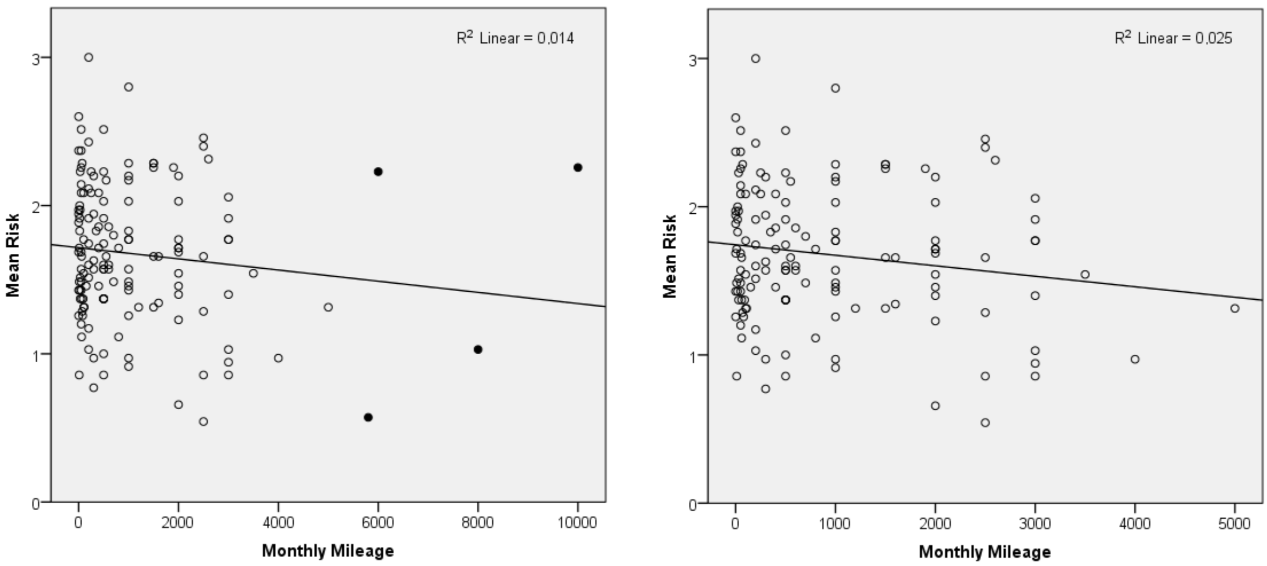


Fig. 2.
Relationship between average perceived risk and monthly mileage, with and without outliers (full dots)

3.6. H4b: There is a negative association between perceived risk and total accumulated mileage (the higher the total mileage, the lower the average risk perception)

Graphs in Fig. 3 display average perceived risk plotted against total accumulated mileage (in kilometres). Based on Pearson correlation coefficient, initially, a weak negative association between perceived risk and total accumulated mileage was found at $\alpha = 0.05$ level (one-tailed $r_{144} = -0.185$, $p = 0.013$). However, the R^2 is close to zero, and upon further inspection, there are 2 outliers in the sample (full dots in the left graph) – the drivers who reported having driven 1.4 and 1.5 million km. After discarding these respondents, the correlation decreases and becomes statistically insignificant (one-tailed $r_{142} = -0.123$, $p = 0.073$). Because the association between the two inspected variables is weak in both cases (R^2 close to zero), and probably influenced by the two respondents with unusually high total monthly mileage, we conclude that there is no association between perceived risk and total accumulated mileage and reject hypothesis H4b.

3.7. H5: There is a negative association between perceived risk and self-assessment of driving skills (the better the grade for the driving skills, the higher the average risk perception).

Based on Spearman correlation coefficient, no association between perceived risk and self-assessment of driving skills was found (one-tailed $\rho_{144} = 0.130$, $p = 0.060$). Therefore, hypothesis H5 is rejected.

3.8. H6: There is a negative association between perceived risk and population of city of residence (the higher the population, the lower the average risk perception)

Based on Pearson correlation coefficient, a significant weak negative association was found between perceived risk and population of city of residence (one-tailed $r_{144} = -0.233$, $p = 0.003$). Solely on these results, hypothesis H6 is accepted. No apparent outliers were identified in the data, however, the association is still low ($R^2 = 0.05$).

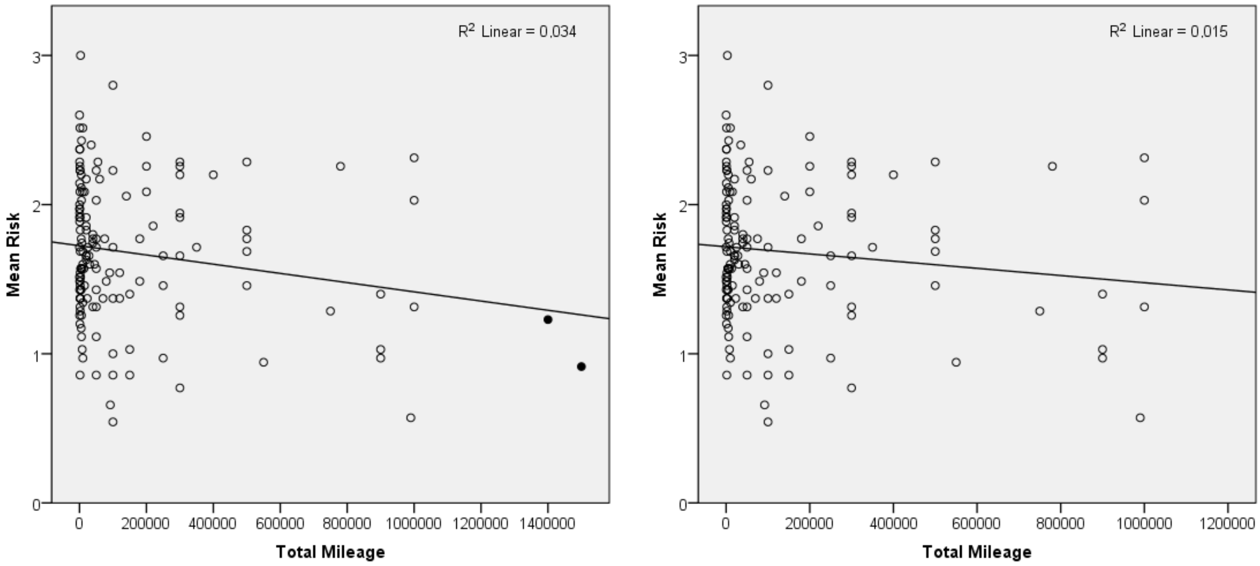


Fig. 3.
Relationship between average perceived risk and total mileage, with and without outliers (full dots)

3.9. H7: There is a difference in average risk perception between the student groups UPOL, VŠLG, ČVUT, the expert group and the group of seniors

Descriptive characteristics are reported in Table 5. Normality assumption of average risk perception was retained for all groups (Shapiro-Wilk test, $p > 0.05$ each), as well as the assumption of homogeneity of variances (Levene's test, $F_{4,\ 139} = 1.429$, $p = 0.228$). Using the one-way analysis of variance, at the significance level of 0.05, no difference was found between the student groups UPOL, VŠLG, ČVUT, the expert group and the group of seniors ($F_{4,\ 139} = 1.765$, $p = 0.139$; see Fig. 4). Therefore, hypothesis H7 is rejected.

Table 5
Descriptive characteristics for testing of hypothesis H7, using Shapiro-Wilk (S-W) test

	N	**Mean**	***SD***	**S-W test**	**Sig.**
VŠLG	55	1.79	0.50	0.986	0.754
ČVUT	24	1.56	0.38	0.976	0.819
UPOL	19	1.51	0.39	0.960	0.572
Seniors	22	1.64	0.57	0.975	0.831
Experts	24	1.70	0.43	0.946	0.219

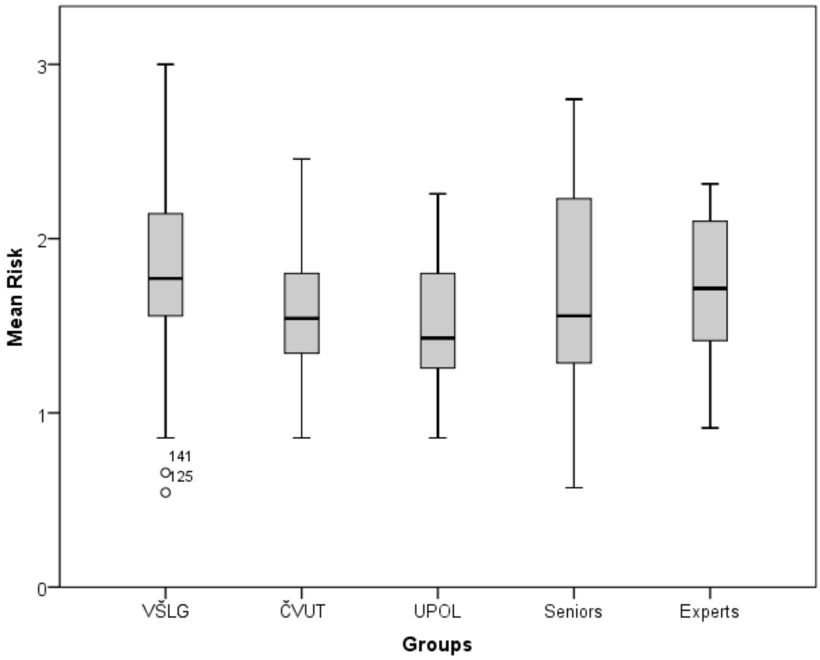


Fig. 4.
Average perceived risk of traffic situations for individual respondent groups

4. Discussion

The results of previous hypotheses testing are summarized and discussed in the following paragraphs:

- *(H1) On average, females perceive the risk of traffic situations as higher than males*. This finding is consistent with earlier studies, which indicated that males tend to be more optimistic regarding their driving skills and perceive the behaviours as less serious and less likely to result in accidents (DeJoy, 1992; Farrand and McKenna, 2001; De Craen et al., 2011).

- *(H2) No difference was found between drivers and "other road users" (pedestrians/cyclists) in their average risk perception.* While it appears as surprising, this may be caused by the fact that most of video clips displayed interactions between vehicles. It means that the respondents, who identified themselves as primarily pedestrians or cyclists, may perceive the risk as related to vehicle drivers rather than to themselves. Nevertheless this is not supported by theory, since neither cyclists' risk perception nor comparisons to drivers' risk perceptions have been sufficiently studied so far, as indicated e.g. by Chaurand and Delhomme (2013) or Lehtonen et al. (2016).

- *(H3a) No association was found between perceived risk and age* and *(H3b) No association was found between perceived risk and years of holding a driving licence*. These findings are not consistent with general knowledge that hazard perception is related to age and experience (Finn and Bragg, 1986; Sagberg and Bjørnskau, 2006; Borowsky et al., 2009), which both contribute to over-involvement of young drivers in accidents. This might be caused by research sample bias, as the sample is rather small and consists mainly of students (younger participants) and traffic experts (older participants). Hypothesis then might be, that both groups perceive traffic risk at the same or similar level, but due to different reasons: young people because of their age (they are known to rather underestimate risk) and traffic experts (older drivers) because of their experience (belief that they can handle such a situation).

- *(H4a) There is no association between perceived risk and average monthly mileage* and *(H4b) There is no association between perceived risk and total accumulated mileage*. Similarly to hypotheses H3a and H3b, we did not find sufficient evidence for the association of driving experience and risk perception in traffic situations in our sample. This could be the result of the aforementioned sample bias – most participants (85%) in our sample reported driving 2000 km or less on average per month and having driven 35000 km or less in total. A less restricted sample in terms of driving experience (i.e., including more professional drivers) might yield different results and become more consistent with existing literature.

- *(H5) No association between perceived risk and self-assessment of driving skills was found.* This finding is not surprising, since literature is mixed on this topic: some studies reported positive correlations, some negative, some none (e.g. Hattaka et al., 1997; Lund and Rundmo, 2009). We expected negative correlation between self-assessment of driving skills and level of risk perception: the better the grade drivers give themselves (with "1" meaning "excellent"), the higher the average risk perception (i.e. the more aware the drivers are of the traffic risk). One of the reasons why this relationship is so unclear might be the fact that most of the studies (including ours) did not distinguish between risk perception ("if I can identify risk, I can see the risk") and ability to handle the risk ("I perceive risk, but I believe I know how to handle it and so I don't consider this situation as risky").

– *(H6) A negative association between perceived risk and population of city of residence was found.* This finding may relate to possible differences in traffic performance and patterns in less vs more inhabited areas. Previous analyses, based on place of residence (as opposed to place of accident) shown that the risk is lower for city population compared to suburban and rural population (Blatt and Furman, 1998; Scheiner and Holz-Rau, 2011). These differences may have been translated to driving behaviour and skills, and in turn to hazard perceptions of users living in cities. However, we should keep in mind that the association in our sample was still rather weak.

– *(H7) No difference was found between the student groups UPOL, VŠLG, ČVUT, the expert group and the group of seniors in terms of average risk perception.* This hypothesis was originally formulated with the idea of checking the anticipated value of expert judgment, which is applied by certified auditors during road safety inspections. Lack of difference may be surprising; however there were previous studies aiming in the same direction. For example Sivak et al. (1989) did not find any differences in risk ratings of professional vs non-professional drivers; also Kouabenan (2002) found similar hazard perception patterns across various occupation and experience groups. In another study (Kruysse and Wijlhuizen, 1992), experts and lay persons were found equally reliable in judging hazardous traffic situations. These features may influence the expert judgments, in addition to already known biases, such as reliability between experts, confirmation of expectancies or skewed descriptive analyses, which are all important elements in road safety inspections and investigations. Although solutions were proposed (Melcher et al., 2001; Cafiso et al., 2006; Elvik, 2006; Washington et al., 2009; Brenac et al., 2012; Park and Sahaji, 2013; Classen et al., 2015), they have not yet become a standard practice.

It should also be noted that the presented study had limitations, which may influence the results and their interpretation:

– Sample size was low, which limited possibility of validation; in addition distribution was skewed towards students. In three of five groups males were overrepresented compared to females.
– The questionnaires were not designed to distinguish between risk perception and ability to handle the risk.
– Video clips of traffic scenes were taken "off-road", which may reduce comparability with previous studies that were typically from the driver perspective. In other words: in the present study, respondents assessed the risk to others, while most studies dealt with risk to respondents themselves. Perceived risks in these perspectives may differ, as noted for example by Sjöberg (2000).
– Pearson correlation coefficients for H3, H4 and H6 were rather low.

5. Summary and conclusions

The study objective was to reveal the links between subjective risk assessment and personality traits – the authors wanted to find an answer to the question *How do we perceive traffic risk?* To this end an on-line test was prepared, consisting of general questionnaire, risk perception assessment, personality questionnaire, and Driver Behaviour Questionnaire. Several groups of respondents filled in the test and their data were analysed.

Some of the identified relationships provided expected results, consistent with previous studies: for example high risk perception of females compared to males or lack of differences between students (non-professionals) and experts (professionals). Other findings were less expected, for example lack of relationships of risk perceptions to age and experience. These could have been influenced by small size of respondent sample or the fact that video clips, used for risk perception assessment were "off-road", as opposed to typical "on-road" design, which could limit comparability to past research.

Nevertheless the idea of the "off-road" video clips was to mimic the view of traffic experts, who conduct road safety inspections, i.e. "ordinary periodical verifications of the characteristics and defects that require maintenance work for reasons of safety" (European Directive 2008/96/EC). The inspections involve survey and reporting with use of check lists, optionally including traffic conflict observations, speed measurements or accident analyses. All these task are to some extent subjective, i.e. possibly influenced by risk perceptions. In this regards the identified differences, based for example on gender or city population, should be considered. Future improved studies may lead to implementation of these aspects in order to improve road safety auditors' or traffic conflict observers' training procedures.

Acknowledgements

We thank Tomáš Režňák (CDV) for developing on-line test interface, and the respondents for participation in data collection. We acknowledge help of the following persons with arrangement of respondents: Michal Turek (VŠLG), Karel Kocián and Tomáš Padělek (ČVUT), Jaroslav Konečný (VPŠ), Ilona Prausová (ČVUT alumni association), Eva Blažková (UPOL Alumni Club). The study benefited from using research infrastructure of Transport R&D Centre (CZ.1.05/2.1.00/03.0064).

References

af Wåhlberg, A.E. 2001. The theoretical features of some current approaches to risk perception, *Journal of Risk Research*, 4: 237-250.

Ambros, J.; Havránek, P.; Valentová, V.; Křivánková, Z.; Striegler, R. 2016. Identification of hazardous locations in regional road network – comparison of reactive and proactive approaches, *Transportation Research Procedia*, 14: 4209-4217.

Ambros, J.; Turek, R.; Paukrt, J. 2014. Road safety evaluation using traffic conflicts: Pilot comparison of micro-simulation and observation. In *Proceedings of International Conference on Traffic and Transport Engineering (ICTTE 2014)*, 221-227.

Andres, J.; Kratochvílová, S.; Křenek, J.; Rücker, J.; Poláčková, K.; Turošíková, B.; Frič, J.; Plánka, L.; Krtička, M. 2012. Experience from In-Depth Analysis of Road Accidents, *Transactions on Transport Sciences*, 5: 171-178.

Armsby, P.; Boyle, A.J.; Wright, C.C. 1989. Methods for assessing drivers' perception of specific hazards on the road, *Accident Analysis and Prevention*, 21: 45-60.

Blatt, J.; Furman, S.M. 1998. Residence location of drivers involved in fatal crashes, *Accident Analysis and Prevention*, 30: 705-711.

Borowsky, A.; Oron-Gilad, T.; Parmet, Y. 2009. Age and skill differences in classifying hazardous traffic scenes, *Transportation Research Part F*, 12: 277-287.

Brenac, T.; Clabaux, N.; Perrin, C. 2012. Qualitative judgements of resemblance between road accident cases: what degree of agreement among experts? *Advances in Transportation Studies*, 26: 89-96.

Cafiso, S.; La Cava, G.; Montella, A.; Pappalardo, G. 2006. A Procedure to Improve Safety Inspections Effectiveness and Reliability on Rural Two-Lane Highways, *The Baltic Journal of Road and Bridge Engineering*, 1: 143-150.

Černochová, D.; Rudá, A. 2016. *TVP – Inventář dopravně relevantních charakteristik osobnosti.* Hogrefe-Testcentrum, Prague, Czech Republic.

Chaurand, N.; Delhomme, P. 2013. Cyclists and drivers in road interactions: A comparison of perceived crash risk, *Accident Analysis and Prevention*, 50: 1176-1184.

Cho, G.; Rodríguez, D.A.; Khattak, A.J. 2009. The role of the built environment in explaining relationships between perceived and actual pedestrian and bicyclist safety, *Accident Analysis and Prevention*, 41: 692-702.

Classen, S.; Yarney, A.K.A.; Monahan, M.; Winter, S.M.; Platek, K.; Lutz, A.L. 2015. Rater reliability to assess driving errors in a driving simulator, *Advances in Transportation Studies*, 36: 99-108.

De Craen, S.; Twisk, D.A.M.; Hagenzieker, M.P.; Elffers, H.; Brookhuis, K.A. 2011. Do young novice drivers overestimate their driving skills more than experienced drivers? Different methods lead to different conclusions, *Accident Analysis and Prevention*, 43: 1660-1665.

Deery, H.A. 1999. Hazard and risk perception among young novice drivers, *Journal of Safety Research*, 30: 225-236.

DeJoy, D.M. 1992. An examination of gender differences in traffic accident risk perception, *Accident Analysis and Prevention*, 24: 231-246.

Elvik, R. 2006. New Approach to Accident Analysis for Hazardous Road Locations, *Transportation Research Record*, 1953: 50-55.

Farrand, P.; McKenna, F.P. 2001. Risk perception in novice drivers: the relationship between questionnaire measures and response latency, *Transportation Research Part F*, 4: 201-212.

Finn, P.; Bragg, B.W.E. 1986. Perception of the risk of an accident by young and older drivers, *Accident Analysis and Prevention*, 18: 289-298.

Hattaka, M.; Keskinen, E.; Katila, A.; Laapotti, S. 1997. Self-reported driving habits are valid predictors of violations and accidents. In Rothengatter, T.; Vaya, E.C. (Eds.), *Traffic and Transport Psychology: Theory and Application*. Pergamon, New York, USA, 295-303.

Hendricks, D.L.; Fell, J.C.; Freedman, M. 2001. *The Relative Frequency of Unsafe Driving Acts in Serious Traffic Crashes: Summary Technical Report*. Report DOT HS 809 205. National Highway Traffic Safety Administration, Washington, USA.

Kanellaidis, G.; Dimitropoulos, I. 1994. Subjective and objective evaluation of risk on roadway curves. *Traffic Engineering and Control*, 55: 451-454.

Kouabenan, D.R. 2002. Occupation, driving experience, and risk and accident perception. *Journal of Risk Research*, 5: 49-68.

Kowtanapanich, W.; Tanaboriboon, Y.; Chadbunchachai, W. 2006. Applying public participation approach to black spot identification process – A case study in Thailand, *IATSS Research*, 30: 73-85.

Kruysse, H.W.; Wijlhuizen, G.J. 1992. Why are experts not better in judging the danger of filmed traffic conflicts? *Accident Analysis and Prevention*, 24: 227-235.

Lehtonen, E.; Havia, V.; Kovanen, A.; Leminen, M.; Saure, E. 2016. Evaluating bicyclists' risk perception using video clips: Comparison of frequent and infrequent city cyclists, *Transportation Research Part F*, 41: 195-203.

Lim, P.C.; Sheppard, E.; Crundall, D. 2013. Cross-cultural effects on drivers' hazard perception, *Transportation Research Part F*, 21: 194-206.

Lipovac, K.; Nešić, M.; Tešić, M.; Ross, A.; Tubić, V.; Marić, B. 2016. A comparative analysis of dangerous locations on the public roads in Serbia, *Safety Science*, 84: 190-200.

Lund, I.O.; Rundmo, T. 2009. Cross-cultural comparisons of traffic safety, risk perception, attitudes and behaviour, *Safety Science*, 47: 547-553.

McKenna, F.; Crick, J. 1997. *Developments in hazard perception*. TRL Report 297. Transport Research Laboratory, Crowthorne, UK.

Melcher, D.J.; Dixon, K.K.; Washington, S.; Wu, C.-H. 2001. Feasibility of "Subjective" Engineering Assessments of Road Safety Improvements: Bayesian Analysis Development, *Transportation Research Record*, 1758: 36-43.

Nordfjærn, T.; Jørgensen, S.; Rundmo, T. 2011. A cross-cultural comparison of road traffic risk perceptions, attitudes towards traffic safety and driver behaviour, *Journal of Risk Research*, 14: 657-684.

Park, P.Y.; Sahaji, R. 2013. Safety diagnosis: Are we doing a good job? *Accident Analysis and Prevention*, 52: 80-90.

Peltz, D.C.; Krupat, E. 1974. Caution profile and driving record of undergraduate males, *Accident Analysis and Prevention*, 6: 45-58.

Reason, J.; Manstead, A.; Stradling, S.; Baxter, J.; Campbell, K. 1990. Errors and violations: a real distinction? *Ergonomics*, 33: 1315-1332.

Sagberg, F.; Bjørnskau, T. 2006. Hazard perception and driving experience among novice drivers, *Accident Analysis and Prevention*, 38: 407-414.

Scheiner, J.; Holz-Rau, C. 2011. A residential location approach to traffic safety: Two case studies from Germany, *Accident Analysis and Prevention*, 43: 307-322.

Sivak, M.; Soler, J.; Tränkle, U.; Spagnhol, J.M. 1989. Cross-cultural differences in driver risk-perception, *Accident Analysis and Prevention*, 21: 355-362.

Sjöberg, L. 2000. Factors in Risk Perception, *Risk Analysis*, 20: 1-12.

Sørensen, M.; Mosslemi, M. 2009. *Subjective and objective safety – the effect of road safety measures on subjective safety among vulnerable road users*. Report 1009/2009. Institute of Transport Economics, Oslo, Norway.

Spicher, B.; Hänsgen, K.-D. 2003. *TVP – Test zur Erfassung verkehrsrelevanter Persönlichkeitsmerkmale*. Hogrefe, Göttingen, Germany.

Šucha, M.; Šrámková, L.; Risser, R. 2014. The Manchester driver behaviour questionnaire: self-reports of aberrant behaviour among Czech drivers, *European Transport Research Review*, 6: 493-502.

Treat, J.R.; Tumbas, N.S.; McDonald, S.T.; Shinar, D.; Hume, R.D.; Mayer, R.E.; Stansifer, R.L.; Castellan, N.J. 1979. *Tri-level Study of the Causes of Traffic Accidents: Final Report – Executive Summary*. Report DOT HS 805 099. National Highway Traffic Safety Administration, Washington, USA.

Vlakveld, W.P.; Goldenbeld, C.; Twisk, D.A.M. 2008. *Perception of lack of traffic safety: An exploration of subjective safety*. Report R-2008-15. SWOV Institute for Road Safety Research, Leidschendam, the Netherlands.

Washington, S.; Lord, D.; Persaud, B. 2009. Use of Expert Panels in Highway Safety: A Critique, *Transportation Research Record*, 2102: 101-107.

Watts, G.R.; Quimby, A.R. 1980. *Aspects of road layout that affect drivers' perception and risk taking*. Laboratory Report 920. Transport and Road Research Laboratory, Crowthorne, UK.

Żakowska, L. 1995. The effect of environmental and design parameters on subjective road safety – a case study in Poland, *Safety Science*, 19: 227-234.

UE GUIDELINES: RISK ASSESSMENT AND RISK MANAGEMENT FOR RAILWAY TRANSPORT

Giovanni Battista Ravera[1], Daniele Muschietti[2], Matteo Ravera[3]
[1,2] *ANSF – Agenzia Nazionale per la Sicurezza delle Ferrovie (National Railway Agency), 50100, Firenze, Italy*
[3] *Freelance, Risk Analysis for Business Expert, 50100, Firenze, Italy*

Abstract: UE guidelines prescribe the harmonization of the safety rules for the infrastructure manager and railway undertakings which must take the full responsibility of the safety, even by implementing measures for the risk control. The Member States do a clear distinction between the safety responsibility and the task of safety authorities to elaborate a national regulatory framework and to monitor the operators performances. Manufacturers, maintenance services suppliers, maintenance of wagons operators, services suppliers and contractor agencies are involved in the safety responsibility of the infrastructure manager and railway undertakings. Infrastructure manager and Railway undertakings work out their own safety management systems to fulfill the CST (Common Security Target), that it is in compliance with the national safety rules as per the directive 2004/49 (now directive 2016/798), as well as the TSI safety standards, that the points relevant to the CSM have been applied (Regulations UE 1169/2010 and 1158/2010).

Keywords: risk analysis, safety indicators, cost-benefit analysis.

1. Introduction

Let's start with some definitions, someone are listed in ISO 31000:

RISK	Effect of uncertainty on objectives; the uncertainty is the state, even partial, of the absence of information concerning the understanding and knowledge of an event, of its consequences and their likelihood. It is a probabilistic concept.
RISK MANAGEMENT	it is an coordinated activity to direct and control an organization about the risk management.
POLICY FOR RISK MANAGEMENT	it is a declaration of the guidelines and operational policies of an organization about the risk management.
RISK MANAGEMENT PLAN	it is a schema (plan) that specifies the approach, the management components and resources to be used for risk management.
RISK MANAGEMENT PROCESS	it is a systematic application of policies, procedures and management processes of communication , consultation, definition of context and identification, analysis, weighting, treatment, monitoring and risk review.
MONITORING OF RISK	it is a constant checking, supervision, critical observation and continuous determination of the state to changes compared to the level of performance required and expected .
RISK REVIEW	it is an activity carried out to detect the suitability, adequacy and effectiveness of something and achieve their objectives.

The infrastructure managers and railway companies shall implement their own safety management systems to fulfill CST (Common Safety Targets), in accordance with the national safety standards according to the Directive 49/2004, as well as the safety regulations TSI, for which are applied the relevant points for the CSM (EU regulations 1169/2010 and 1158/2010). Between these points, the following criteria are listed:

A The control measures for the risks linked to the activity of the operator rail;
B The control risk related to the supply of material and maintenance;
C The control of risk related to the use of contractors and suppliers;
D The risks coming from activities of other parties external to the railway system;
M Procedures and methods to perform risk assessment and risk control for every change in operating conditions or changes of railway systems.

[1] Corresponding author: gbravera@gmail.com

2. Ue guidelines

An organization that subscribes a policy for risk management, coherent with its cultural principles, must determine the performance indicators in line with other strategic indicators and align the objectives of risk management with the business plan already identified, ensuring the respect of requirements.
The EU Directive 2004/49 (now EU 2016/798) regulates the safety of the railways in European Union. The same Directive introduces the indicators, methods and common safety targets (CSI, CSM, CST) to allow to develop and manage the railway safety in a harmonized way. In particular, the common safety targets (CST) are expressed in terms of risk acceptability or levels of safety objectives, and they are valued by the common safety indicators (CSI) considering the INDIVIDUAL RISKS and the RISKS FOR THE COMMUNITY.
About the SGS, the Directive attributes to the GI to IF responsibilities regarding risk control, internal and external, or induced by contractors.

Table 1
The risk management by directives EU

UE GUIDELINES
Common Safety Indicator CSI
Common Safety Method CSM
Common Safety Target CST

Risk control is a chore that competes also to all actors that have an impact on the safe operation of the EU rail system, including: manufacturers, maintenance service providers, owners, contracting authorities, etc.
Moreover, for the latter it is necessary to ensure the compliance with the requirements and conditions of use required for all exercises, materials and supplied services.
In the case of safety risks due to defects, construction non-conformities, or malfunctions of technical equipment, also of structural subsystems, the infrastructure managers (IM) and Railway Companies (RU) need to put in place the necessary corrective measures to cover the risk of security identified and reported this risk to stakeholders to allow to take the necessary additional corrective measures.
All this to ensure the safe operation of the rail system and facilitate the exchange of information between relevant actors.
As mentioned, the control of risk is expressed in terms of the safety target levels or risk acceptability, through the CST, regulated by appropriate CSM to be taken to ensure the objectives of safety, and CSI to evaluate the realization of the same goals .
The CSMs shall describe the evaluation of the levels and the achievement of safety goals through the development and adoption of methods for risk assessment, evaluation of compliance with the safety certification requirements, supervision and monitoring , applied by the national authorities security, performance assessments of rail operators, the evaluation of the realization of safety targets and all other relevant methods SGS to be authorized at EU level.
The CSM are prepared by ERA, on the basis of user opinions, by NSA and stakeholders, possibly including the social partners on consultative mandate of the EC.
The document drafted by ERA on the CSM represent a EC recommendation and consists of a report on the consultation results and a report on the impact assessment of new or modified CSM to be taken.
The CSM are subject to periodic reviews subsequent to experiences gained from their application or the global evolution of railway safety. The content of the CSM and any amendments may be adopted by the EC to issue its delegated acts.
The CST establish minimum safety levels that must be expressed by the rail system as a whole and from different parts of the rail system of each Member State of the EU.
The CST can be defined in terms of risk acceptance criteria or objective level for the security considering the individual risks they are exposed to all stakeholders and the risks for the company.
Even the CST are processed by ERA by mandate of the EC.
The recommendations ERA in approving SCST can be transposed from the EC by implementing acts. For this reason, the EC shall be assisted by an advisory committee that gives advice on ERA's recommendations.
Even the CST are subject to periodic reviews like the CSM.
All national regulations on safety must comply with the CST and CSM.
The NSA must verify that the IFs and GIs, including all concerned stakeholders, acquire a strict liability on the definition of a functional to a SGS project.
The SGS objectives should aim to identify associating dangers to control activities of all their components, engines and the risk that each individual can represent danger to the safety and operation.
Based on these assessments must develop strategies to reduce the probability and frequency of occurrence of each risk, to bring them to an acceptable level.

This is achieved, as already mentioned, by means of a correlation between the CSI and the CST, applying the CSM whose synthesis represents the SGS manual.

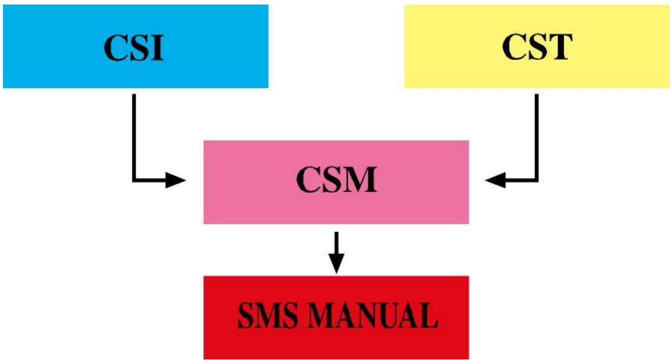


Fig. 1.
Correlation between CSI & CST

Therefore it needs to be developed a program of activities that will ensure that all security requirements are identified and implemented.

3. Factors causing the risk

DANGER: probability that it is reached the potential level of damage.
The danger is constituted by three basic components:

1. Hazard Element (HE) = it is the main source of danger, one that can generate the unexpected event;
2. Initianing Mechanism (IM) = it is the mechanism that causes the transformation from dormant state to the active state;
3. Target and Threat (T / T) = it is the damage /hurt that can suffer one thing / person exposed to the incident.

Fig. 2.
The danger triangle

Therefore a dangerous event can have harmful consequences only when it activates all the three components, or with other words in the moment when there is the simultaneous presence of the three components is the concrete risk of a dangerous occurrence.
In complement, the mere absence of one of the components makes it unlikely that the dangerous event activation. It follows that inhibition of one of the three components has an effect relieved / preventive on the risk of occurrence.

Table 2
Same risk examples. The free components HE, IM, T/T may be considerated as the triangle segmentes: if anyone there is not, the danger disappeared

HE	IM	T/T
- Track geometry defect;	- Prud'Homne limit Override; - Sidling limit Override;	- Railway vehicle Derailment, - Infrastructure Damage; - vehicles ehicles Damage; - Personal injury; - Environmental damage; - etc……..
- CCS subsystem	- Unreliability security	- Convoy clash;

degradation on less restrictive levels of ordinary ones; - Fail safe out of service;	apparatus; - Human error by staff responsable;	- Damage to third parties; - Personal injury; - Infrastructural Damage; - etc…..

The status of a danger remains latent until it gets a trigger that activates the transition from danger in an accident.
Two factors that influence the transition:

- The overall level of risk;
- The risk rate of each individual component.

It follows that the danger of components are the elements of definition of the same hazard and the risk of accident is the probability that a danger cause an event of a certain severity.

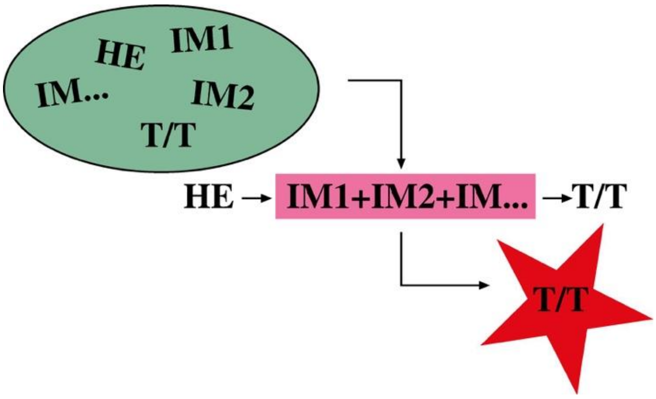


Fig. 3.
The incident birth

To summarise, the accident can happen only if the three components of the danger, consisting of one or more elements are aligned on a specific configuration at the same time.
This means that all the causality of the danger components will not cause the accident until the interaction will not assume a predefined sequence.
The three components can be all causes of accidents independently of the order with which they appear.

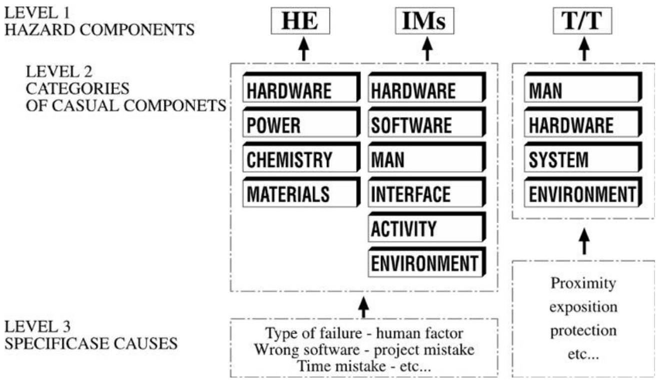


Fig. 4.
Factors causing the danger. The level 1 is the top level and includes the components of danger (HE + IM + T/T). 2 level is the intermediate containing the categories of factors causing the danger (HCF). The level 3 represents the lower level where all detail items of specific causes of danger are placed.

The hazard causal factors (HCF) may be present in a system, because they are inevitably used by the system and / or because the conceptual assumptions of the project was inadequate, or because induced by an exogenous source to the system.
The analysis of the cause of the danger factors is the basic principle of the theory DANGER-STEP, which can be summarized as follows:
The danger due the accident; a hazard is a condition that defines a possible future event (accident);
A danger and an accident are two different states of some phenomena (before and after);
Each hazard / accident has its own and unique risk (probability and frequency);
A danger is an entity identified by three components (HE + IM + T / T);

HE and IM are the factors of the causes of danger and define the probability factor of the risk of accident;
T / T with parts of HE and IM define the severity factor of the risk of accident;
HCF (hazard causal factors) can be characterized by three different levels;
h. the probability that a hazard exists is "1" or "0"; However, the probability that happen an accident is linked to the specificity of the HCF.

4. Risk management

Risk management explicitly addresses uncertainty, its nature and its treatment.
The basic principles to allow for effective risk management does not transcend the value of the organization and management processes, are part of the decision-making process by helping managers to make informed choices, through priority stairs, about possible alternative actions.

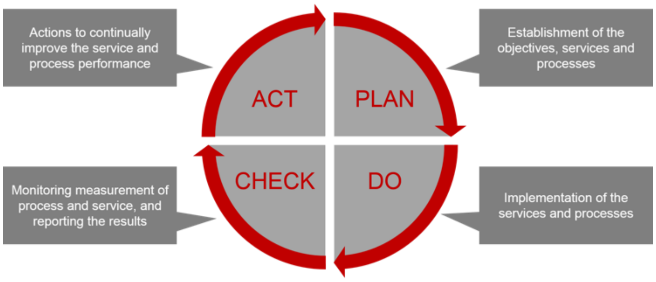


Fig. 5
The risk management is an activity in "perpetuo motu"

The approach to the risk management must be structured, systematic and timely; this allows to make efficient the action through the consistency of the results to be comparable and reliable.
An effective risk management is based on reliable information, clear and, as far as possible repeatable.
The historical data, the experience feedback, the comments, the specialist studies are Input elements for the analysts.
The risk management must be always contextualized to internal and external events of the organization, according to a predefined risk profile, and must consider the human and cultural factors that can facilitate or impede the achievement of the objectives.
All stakeholders must be involved in risk management so as to make it transparent and inclusive more as possible.
An effective risk management caused a continuous improvement of the organization or the company, responding to the stress of change in a dynamic, iterative and responsive way; whenever the external and internal events change the context and knowledge, it should be implemented to monitor and review, to detect new risks or the changing and the disappearance of some other risks.

5. Instruments for risk management

The creation of appropriate safety case provides a means to demonstrate that the planned activities were implemented successfully, achieving the risk reduction objectives.
For a certification / authorization, the NSA should verify the consistency of the processes implemented by the IF and GI, that requiring the certification, in particular they should delay on the implementation and on the consistency of the following activities:

a. Preliminary Hazard Analysis (PHA);
b. SGS Manual: must detail the strategies for reducing risks to an acceptable level established by applying the CIS and the CST;
c. Hazards Analysis (HA and Hazard log): Check on starting a hazard analysis and creating and maintaining the register of the dangers;
d. Plan of monitoring: preparation of audits / inspections / Process Security checks to verify compliance of security activities with SGS and any other required standard;
e. Specification of security requirements (organizational procedures, operational procedures): specific safety requirements derived from the risk reduction strategies must be fully available for the audit work / inspections / checks by setting up appropriate procedures;
f. Validation of security requirements: he appropriate testing procedures must be developed to validate the safety requirements;
g. Safety case: is a documentary process that tests the security processes to capture information on the effectiveness of control and risk management.

In the following, we delay the attention on the first three activities.
The Hazard Analysis (PHA and HA) has as its objective the identification of hazards and hazardous events, for all reasonably foreseeable circumstances, including the misuse and fault conditions, and the definition of the causes for

analyzing the sequence of events in appropriate combinations. This must lead to the determination of the risks associated with dangers.
The Hazard Analysis is therefore an iterative process that continues throughout the life of the system, designed to identify and mitigate hazards that may be induced by the relevant activity of design, development, testing, functional testing, maintenance and disposal (sale) of a system. A fundamental document, result of the Hazard Analysis, is the Hazard Log (Register of dangers). In this, for every danger, are recorded the results of a Hazard Analysis process development steps, including specific mitigation or prevention actions.

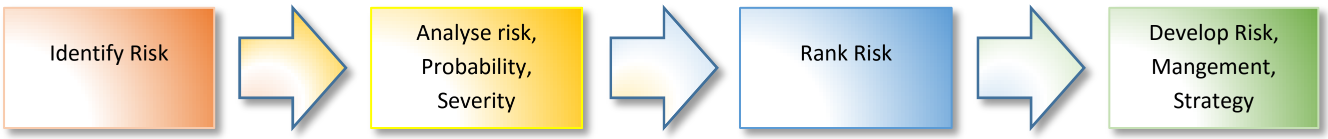


Fig. 6.
Hazard analysis block flow

The procedural flow of the Hazard Analysis can be simplified into the following macro-actions:
i. identify,
ii. then analyze,
iii. then classify
iv. and, at the end, advancing!

The first step identifies the scenarios and the dangers qualifications and corresponds to the block "Identify Risk". The steps 2 and 3 analyze the dangers and define its connotation in terms of scenarios (Si), the probability of occurrence (Lj) and harmful consequences (Xk); the risk of occurrence is represented by this set of three vectors:

$$\text{Risk} = \{< S_i, L_i, X_i >\} \quad (1)$$

The steps 2 and 3 are identified in the block "Risk Analyse, Probability, Severity," while the step 4 is represented by the block "Rank Risk". Step 5 is the block generator "Develop Risk, Mangement, Strategy" and conception of the Risk Planning.

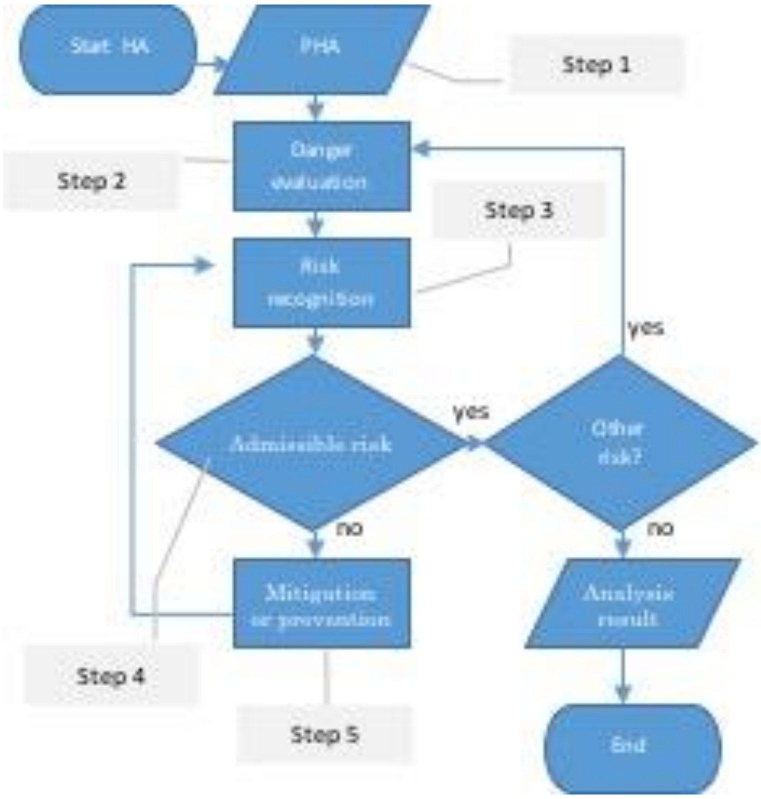


Fig. 7.
Develop of analysis process/risk assessment

Any operating environment directly in engineering of industrial organizational systems is characterized by the presence of real risks. Many can relate the organizational area, other corporate strategies, and of course, many others are relevant to the productive functioning; and in the transport this operation should be safe.

Some scenarios are listed below:
The collapse of an organizational system or part of it (the organizational failures are often the main sources of risk).
Risk of extreme or rare events can be distorted by the only assessments based on the expected value measure (the measure of the expected value of risk for rare but catastrophic events of low probability with other less high probability of adverse events can distort or result in the management of pain catastrophic risk).
The risk of exceeding the project costs and delays of the program (the design of engineering systems is often characterized by the cost overruns and program delays and, therefore, the management process and the risk assessment can be a necessary requirement to prevent ' inability to meet performance criteria).
Risk management is an integration requirement for engineering systems (all aspects, components and functions of the system must rely on an assessment of the associated risks, this ensures a second approximation also an understanding of the functional aspects that emerge as a subprocesses of integration).
The restructuring and maintenance of structural subsystems (the accurate assessment of risk of failure and functional degradation of the structural subsystems is a requirement for the effective allocamento resource).
The overall extent of the failure modes and reliability of engineering systems (there are different types of faults and interpret the consequences is a priority for management and risk assessment).
The risk on the development of intellectual activities in the field of engineering systems (can not be developed the research and yhe technological innovation when the system is beset by problems of cost overruns and production delays).
The risk of unexpected and critical to the security of the system (the assessment and management of risk is not sufficient without the construction of safety-related systems, including ensuring the most remote probability of failure a safe stop without catastrophic consequences).
Engineering system characterized by interdisciplinarity (the engineered systems serve the welfare of the population and the integration of basic knowledge of other disciplines is essential; the risk of bankruptcies on the rise, increasing throughout this interdisciplinary).
Risk management: a requirement for a sustainable development (sustainable development and guarantee secure protection of the environment and ecology, and this can not be achieved without a systemic process of assessment and risk management).
Risk assessment based on evidence (data-base and limited information often characterize systems, especially during the phases of conception, design and implementation; the reliability of the evidence, including those produced by the experts, it is essential for the practical risk management these systems).
impact analysis (a good methodology necessarily incorporates a best practice risk management, in particular the decision implemented today has impact on future decisions and opinions).
The application of hazard-accident theory to some of the risks listed and bringing it to the reality of railway subsystems, can give rise to the examples given in the following table:

Table 3
Application of danger-incident theory about system railway scenarios

HE	IM	T/T
- Evaluation based limitate about expected risk	- Presumption of own infallibily for many experiences; - Statistical elements up or low overestimate; - - etc. …	- Disorientation of corporate strategy and policy; - Bed management of corporate balance sheet; - Wiste production; - etc. …
- Overflow of budget cost; - Delay of manufactoring	- Unsatisfied performances; - Absence of re-examination assessment; - - etc. …	- Bank index redetermination; - Finance charge unknowledge; - Job cost increse; - Productivity decrese; - etc. … -
- Risk management approach not oriented to system and process	- Not available WBS process definition; - - incomplete assessment of process risk	- Total cost unknowledge; - Incident; - Wiste production; - etc. … -

HE	IM	T/T
- Indeterminated functional degeneration; - Indeterminated funzional reset; - Deteriorated operation	- Inadequate policy manufacturing needs; - Mistake application of mantenance engeenering; - Inadequate supply of material and mantenance; - Operative inability; - etc. …	- Lost of manifacturing; - Total cost unknowledge; - Incident; - Damage of materiali and plant; - Injuries; - - etc. …
- Unavailability of manufactoring; - Indetermineted failure; - Technical crash; - Deteriorate operation	- Failures and malfunctionigs; - Operational incompetence; - Human mistake; - - etc. …	- Incident; - Lost of manifacturing; - Unespected repair costs; - Plant damage; - Injuries; - -etc. …

The danger-accident theory tries to give a methodical approach to the application of analysis and evaluation of a set of data, to express in terms of probability of achieving a potential level of damage. Although deterministic, the measurement problem of a risk is linked to statistical concepts and type of decision variables, for which can be a suitable configuration that optimizes the choice of appropriate decisions, in terms of safe operation and secure maintenance.

Fig. 8.
The risk management must be measured

In these cases the math always provides the best opportunity to solution through the application of one of its disciplines. The use of a suitable mathematical model can represent a real system.
Therefore, a mathematical model is a set of equations that describe and represent the real system. This type of equations analyses the various aspects of the problem, it identifies the functional relationships between all the components of the system and the elements of its environment, it lays down measures of effectiveness and constraint, indicating what data should be collected to address the problem qualitatively.
Often mathematical models optimize or solve the problems encountered in real life, through the techniques of optimization or simulation appropriate. For example: the definition of a scenario of optimal decisions, $\{x_1^*, \dots, x_n^*\}$, could result from the maximization (or minimization) of an objective function, $f = f(x_1, \dots, x_n)$

$$\max = f(x_1, \dots, x_n) \tag{2}$$

subject to predetermined constraints,

$$\begin{cases} g_1(x_1, \dots, x_n) \leq b_1 \\ \dots \dots \dots \dots \dots \dots \dots \dots \\ g_n(x_1, \dots, x_n) \leq b_m \end{cases} \tag{3}$$

to summarise: $f(x_1, \dots, x_n)$ is the objective function, $\{x_1, \dots, x_n\} = \vec{X}$ are the decision variables, $g_1(\vec{X}), \dots, g_n(\vec{X})$ are the constraints and $\{b_1, \dots, b_m\} = \vec{B}$ are known as resources.
In the case of linearity of the binding functions, the system of equations can be represented in matrix form:

$$G\vec{X}^T \leq \vec{B}^T \tag{4}$$

and the problem can be solved with the principles of linear programming.
An example of scenario where the implementation of optimized decisions is the functional subsystem maintaining railway infrastructure and rolling stock (locomotives and cars).
The European regulations and national legislation obliging operators to equip themselves with a GSE that contains the provisions and procedures to meet the requirements for the maintenance in a safe condition.
Assuming that these conditions are governed by the decision variables $\{x_1, \ldots, x_n\} = \vec{X}$, you can assume the following system functions:

$$\begin{cases} R = R(\vec{X}, \vec{E}) \\ A = A(\vec{X}, \vec{E}) \\ M = M(\vec{X}, \vec{E}) \end{cases} \tag{5}$$

where $\vec{E}$ is the any exogenous event or stochastic.
Consider then the maintenance system of the structural subsystems Infrastructure (INF) and command / control / signalling (CCS), bound by a number of restrictions:

$$\begin{aligned} &g_1 = g_1(R, A, M, C) \leq K_1, \text{costo funzionamento sicuro;} \\ &g_2 = g_2(R, A) \leq F, \text{rischio avaria;} \\ &g_3 = g_3(R, A, M) \leq T, \text{rischio degrado funzionale;} \\ &g_4 = g_4(M, C) \leq K_2, \text{costo ripristino sicuro.} \end{aligned} \tag{6}$$

Assuming that the objective function is represented by a linear combination of the system functions, the definition of the optimal decisions can be obtained from the minimization of the objective function:

$$\min\{f(R, A, M)\} \Longrightarrow \overrightarrow{X^*} = \{x_1^*, \ldots, x_n^*\} \tag{7}$$

Since the entire analysis is based on the possession of variables and resources derived from concepts and safety rules, it follows that the decisions optimized characterize the safety of maintenance and operation.

6. Cost of risk

In addition to what indicated in Annex I paragraph 5 of the Directive 798/2016, the calculation of the economic impact of accidents, must be considered among the direct and indirect costs also failures.
Damage can always be traced to a mathematical expression, f (faults, failures, accidents), even in the first approximation. In fact there are unexpected costs for both the GI IF when the train does not respect the hours of service, that is late.
What are the causes that may cause a delay when traveling?
Essentially:

- weather;
- damage
- accidents (including those not caused by railway vehicles);
- strikes.

All these unwelcome phenomena involve Additional Costs for both business in general but also for the community.
The basic safety guidelines consider only costs incurred by the GI and IF.
In fact, there are costs to be borne by the EU, individual states, local public administration, And Also for the passengers.
So to optimize the interventions, in addition to requiring the safety rules, it is very important to analyze in a comprehensive and exhaustive manner the risk phenomenon.
How to proceed?

- indicative of potential;
- determine all the possible levels;
- give each level a cost equivalent Ceq, for its elimination;
- at each level of risk of degradation associate hypothetical scenarios;
- to every degradation, quantifying a relapse in economic terms Cd;
- compare Ceq / Cd;
- draw the considerations in terms of corporate image ... it is a choice of enterprise policy.

7. Conclusions

The following is a set of 13 logical steps with which to address problems:

a. Define and generalize the client's needs. Consider the total problem environment. Clearly identify the problem.
b. Help the client determine his or her objectives, goals, performance criteria, and purpose. Similar to step 1; consider the total problem's environment. Evaluate the situation, the constraints, the problem's limitations, and all available resources.
c. Study and understand the interactions among the environment, the technology, the system, and the people involved.
d. Incorporate multiple models and synthesize. Evaluate the effectiveness, and check the validity of the models.
e. Solve the models through simulation and/or optimization.
f. Evaluate various feasible solutions, options, and policies. How does the solution fulfill the client's needs? What are the costs, benefits, and risk trade-offs for each solution (policy option)?
g. Evaluate the proposed solution for the long term as well as the short term. In other words, what is the sustainability of the solution?
h. Communicate the proposed solution to the client in a convincing manner.
i. Evaluate the impact of current decisions on future options.
j. Once the client has accepted the solution, work on its implementation. If the solution is rejected, return to any of the above steps to correct it so that the client's desires are fulfilled.
k. Postaudit your study.
l. Iterate at all times.

References

Commission Implementing Regulation (EU) No 402/2013 of 30 April 2013 on the common safety method for risk evaluation and assessment and repealing Regulation (EC) No 352/2009 Text with EEA relevance.

Commission Regulation (EU) No 1077/2012 of 16 November 2012 on a common safety method for supervision by national safety authorities after issuing a safety certificate or safety authorisation Text with EEA relevance.

Commission Regulation (EU) No 1078/2012 of 16 November 2012 on a common safety method for monitoring to be applied by railway undertakings, infrastructure managers after receiving a safety certificate or safety authorisation and by entities in charge of maintenance Text with EEA relevance.

Commission Regulation (EU) No 1158/2010 of 9 December 2010 on a common safety method for assessing conformity with the requirements for obtaining railway safety certificates Text with EEA relevance.

Commission Regulation (EU) No 1169/2010 of 10 December 2010 on a common safety method for assessing conformity with the requirements for obtaining a railway safety authorisation Text with EEA relevance.

Directive (EU) 2016/797 of the European Parliament and of the Council of 11 May 2016 on the interoperability of the rail system within the European Union (Text with EEA relevance).

Directive (EU) 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety.

Directive 2004/49/EC Of The European Parliament And Of The Council of 29 April 2004 on safety on the Community's railways and amending Council Directive 95/18/EC on the licensing of railway undertakings and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification (Railway Safety Directive).

Regulation (EU) 2016/796 of the European Parliament and of the Council of 11 May 2016 on the European Union Agency for Railways and repealing Regulation (EC) No 881/2004 (Text with EEA relevance).

ESTIMATING THE NUMBER OF TRAFFIC ACCIDENTS, INJURIES AND FATALITIES IN TURKEY USING ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM

Ali Payıdar Akgüngör[1], Ersin Korkmaz[2], Erdem Doğan [3]
[1,2,3] *Civil Engineering Dept., Engineering Faculty, Kırıkkale University, Kırıkkale, Turkey*

Abstract: This study proposes Adaptive Neuro-Fuzzy Inference System (ANFIS) models to estimate the number of accidents, injuries and fatalities in Turkey. In the model development, population (P) and the number of vehicles (N) are selected as model parameters. Three different ANFIS structure models are developed using the data covering from 2000 to 2014. Developed models' results are statistically compared to observed values for training and test data in terms of root mean square errors (RMSE), mean absolute percentage errors (MAPE) and coefficient of determination (R^2). The results of the ANFIS models showed that they was suitable to estimate the number of accidents, injuries and fatalities. To investigate the performance of ANFIS models for future estimations, a ten-year period from 2015 to 2024 is considered. Thus, future values of population was obtained from the projection of Turkish Statistical Institute (TSI) and the vehicle ownership rate is expected to reach 0.4 by 2024. Therefore, population and the number of vehicles are considered to reach approximately 85 and 34 million, respectively. The results obtained from future estimations reveal the suitability of ANFIS approach for road safety applications.

Keywords: traffic accidents, injuries, fatalities, Adaptive Neuro-Fuzzy Inference System (ANFIS), Turkey.

1. Introduction

Deaths and injuries in traffic accidents are serious problems for all countries. The World Health Organization (WHO) reports that worldwide over 3 400 people die and around 120 thousand people are injured or disabled each year because of traffic accidents . The number of deaths and injuries in traffic accidents of a country are directly proportional the level of development of the country. WHO expresses that 90 % of deaths resulted from traffic accidents occur in low and middle income countries, although these countries less than 50% of motor vehicles in the world (WHO, 2011). The poor road conditions, traffic infrastructure, inappropriate mixing of vehicle types, inadequate traffic law enforcement and behavior of road users cause to increase the number of fatalities and injuries in these countries. The roughly estimated cost related to traffic accidents is 1%, 1.5% and 2% of Gross National Product in low, middle and high income countries respectively.

Turkey is a developed country with growing population and economy. Today, the population and income of the country has reached 79 million people and 718.22 billion US dollars. However, the country has a significant burden of road traffic injuries and fatalities. For instance, according to the data of Turkey Statistical Institute (TSI) over 1.3 million traffic accidents happened in the whole country in 2015. 7.5 thousand people lost their lives and almost half of them lost their lives in 30 days after the traffic accidents. Additionally, nearly 305 thousand people injured or disabled in these accidents in 2015 (TSI, 2015). When these numbers are compared with some other Europe countries it is seen that traffic accidents are a serious problem for Turkey. The main reasons of traffic accidents in the country are the lack of awareness, driver and passenger related factors, over speed, cell phone usage during driving, dense freight and passenger traffic on highways, vehicle related factors, inadequate traffic law enforcement etc.

Accident prediction models are widely used decision makers and engineers to predict accident trends and develop new strategies for traffic safety. In the literature, various accident prediction models have been developed by using different assumptions. One of the oldest accident models was developed by Smeed in 1949. He investigated the relationship among death, number of vehicles and population while developing his model. He gathered one year data from 20 different countries to develop the accident model (Smeed, 1949). However, Andreassen deeply criticized Smeed's model. According to Andreassen, one year data was not enough to develop a model and the developed model by Smeed could not be used for 20 countries since each country has different traffic, economic and social parameters. Therefore Andreassen proposed an accident model for each country by using same model parameters (Andreassen, 1985). Jacobs and Hards (1978) studies Smeed's model, and they interestingly found that Smeed's model remained unchanged when the analysis was repeated for the same 20 countries using the 1950, 1960 and 1970 data. Valli (2005) for India and Akgüngör and Doğan (2008) for Turkey adapted the Smeed and Andreassen models to estimate the number of accidents, deaths and injuries. Zegeer and Deacon (1987) developed an accident prediction model by using both traffic, road geometry and terrain condition data. Abdel-Aty and Radwan (2000) used negative binomial distribution to estimate crash frequency by employing traffic and road geometry data. Different accident models for various countries have been proposed by researchers such as Al-Matawah and Jadaan (2009) for the United Arab Emirates, Jordan and Katar, Akgüngör and Doğan (2008) for Turkey, Ackaah and Salifu for Ghana (2011), and Chakrobort and Roy (2005) for India. Russo *et al.* (2014) investigated road safety from the perspective of driver gender and age as related to the injury crash frequency and road scenario. They developed safety performance functions (SPFs) to predict the number of injury crashes using a study on the influence of the human factors and road scenario on effects of a crash by varying the dynamic. It was understood that the age and gender of drivers considered together further refines how those factors contribute to crashes. Russo *et al.* (2016) studied to calibrate Safety Performance Functions (SPFs) that can predict the

[1] Corresponding author: akgungor@kku.edu.tr

frequency per year of injuries and fatalities on homogeneous road segments. A negative binomial regression model was used in this study and results of study confirmed the effectiveness of the SPFs.
In addition to mathematical models, artificial intelligence techniques have lately been utilized to developed accident models in road safety studies. Mussone *et al.* (1999) used artificial neural network (ANN) model to analyze accidents in Milan. ANN technique was also used by Abdelwahab and Abdel-Aty (2001) to predict driver injury severity and by Çodur and Tortum (2015) to estimate highway accidents. Chiou (2006) used ANN-based expert system for car crash accidents. Akgüngör and Doğan (2009) developed ANN and genetic algorithm models to estimate the traffic accidents in Ankara. Korkmaz and Akgüngör (2016) used differential evolution algorithm which is one of the artificial intelligence techniques to develop accident prediction models.
Zaho et al. (2014) used ANFIS to establish a vehicle crash model. Hosseinpour et al. (2013) also proposed an ANFIS technique for modelling traffic accidents as a function of road and roadside characteristics. The candidate set of explanatory variables included the mean horizontal curvature, shoulder width, road width, land use, access points, longitudinal grade, and horizontal curve density. The results showed that shoulder width, road width, land use and access points significantly affected accident frequencies. They found that proposed ANFIS model could be used as a robust approach to transportation safety studies. Hosseinlou and Sohrabi (2009) applied neuro fuzzy systems to predict and identify traffic hot spots on rural roads. They concluded that the stated system could predict 96.85 % of accident frequencies in the studied blocks.
In this study, three accident prediction models (for accident, fatality and injury) for Turkey were proposed based on population (P) and the number of vehicle (N) by using ANFIS. The performance of ANFIS models was evaluated by means of the root mean square error (RMSE), the mean absolute error (MAE) and the coefficient of determination. R^2 for both test and train data. Analysis results showed that all proposed accident models could be used for traffic safety studies.

2. Details Experimental

2.1. Adaptive Neuro-Fuzzy Inference System

ANFIS emerged as a practical application of artificial intelligent approaches for many fields. It was developed by Jang in the early 90's. Basically, it runs as a combination of Fuzzy Logic and Neural Network. In other words, it is a system, which incorporates Sugeno-type fuzzy into adaptive neuro network structure. ANFIS combines the advantages and benefits of fuzzy and neural network to reach optimum solution. To achieve this, the principles of Fuzzy Logic and Neural Network are used together in ANFIS. Rules, fuzzification, inference and neural network structure create the basic steps and structure of ANFIS. The schematic form of fuzzy system is shown in Fig.1.

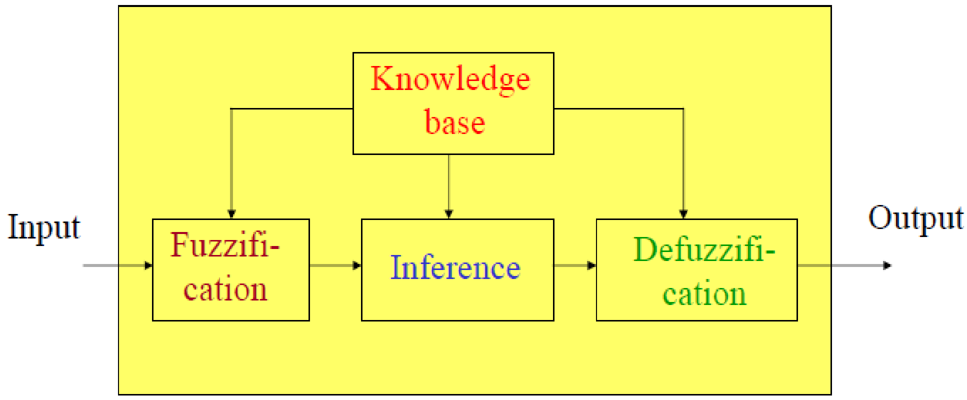


Fig. 1.
Fuzzy System

The output of neural network is determined according to fuzzy system or in other words, rules base. The neural network of fuzzy rule base is illustrated in Fig.2.

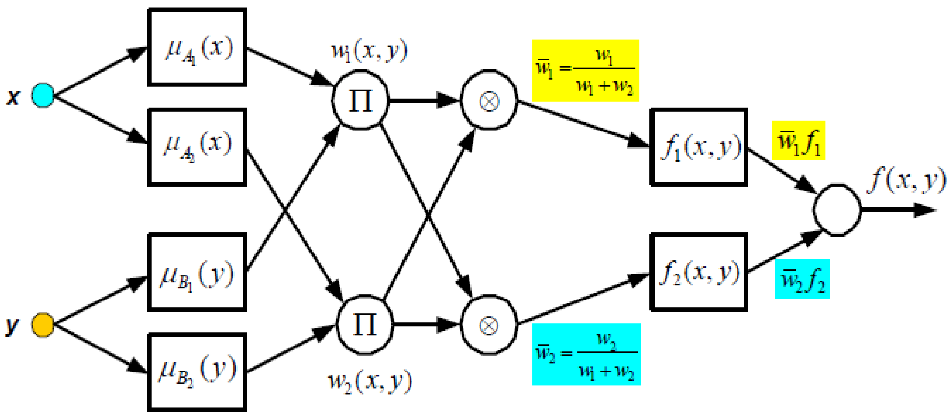


Fig. 2.
Neural Network Structure

2.2. Development of ANFIS model

In order to apply ANFIS for estimating of accidents, injuries and fatalities, determination of input data is a significant step. In the light of previous studies in the literature, ANFIS models for each event were developed depending on two input parameters, which are P and N. These necessary data were obtained from Turkish Statistical Institute (TSI, 2015). Fifteen-year data between 2000 and 2014 were randomly separated into training and test. For this purpose, 11 data were used for training remaining data were utilized for test. According to training data, ANFIS structure were created and run to determine coefficients of network. The structure of ANFIS is illustrated in Fig.3.

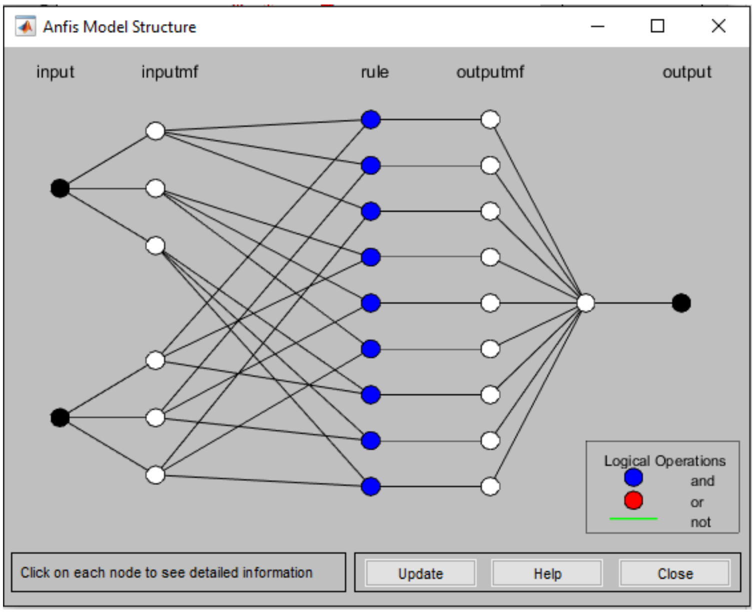


Fig. 3.
The Structure of ANFIS

ANFIS models for accidents, injuries and fatalities were created separately according to training data of each situation. 9 rules base were generated by ANFIS according to input and output data. The rules base is showed in Fig.4-6 respectively. In Fig.3 and Fig.7, input 1 is population and input 2 is the number of vehicles respectively. The distributions of training data are shown in Fig.7.

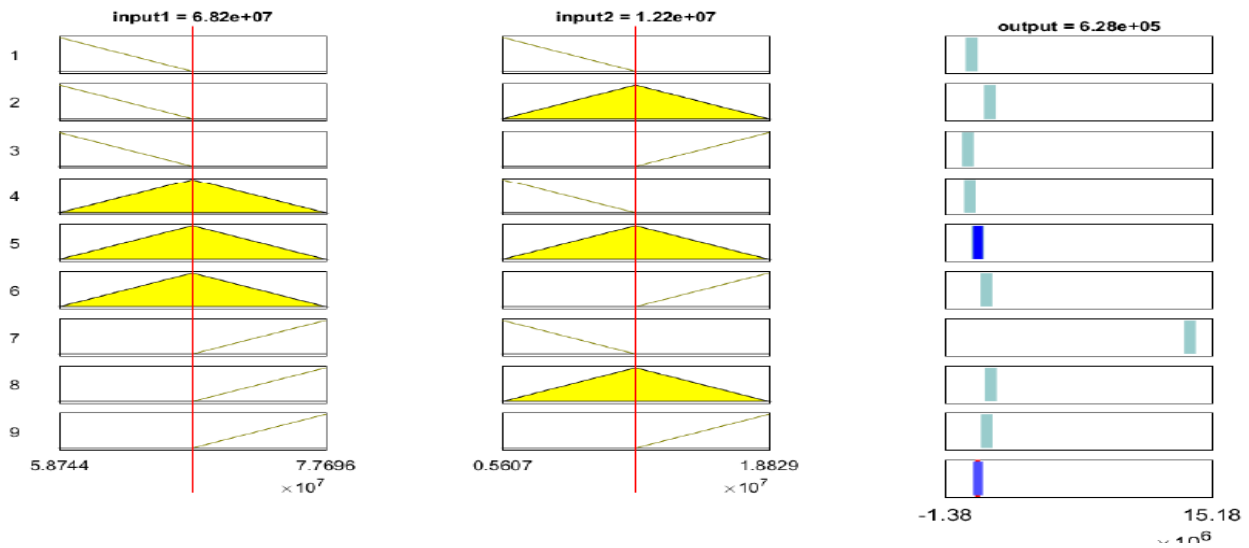


Fig. 4.
Rules Base of Accidents

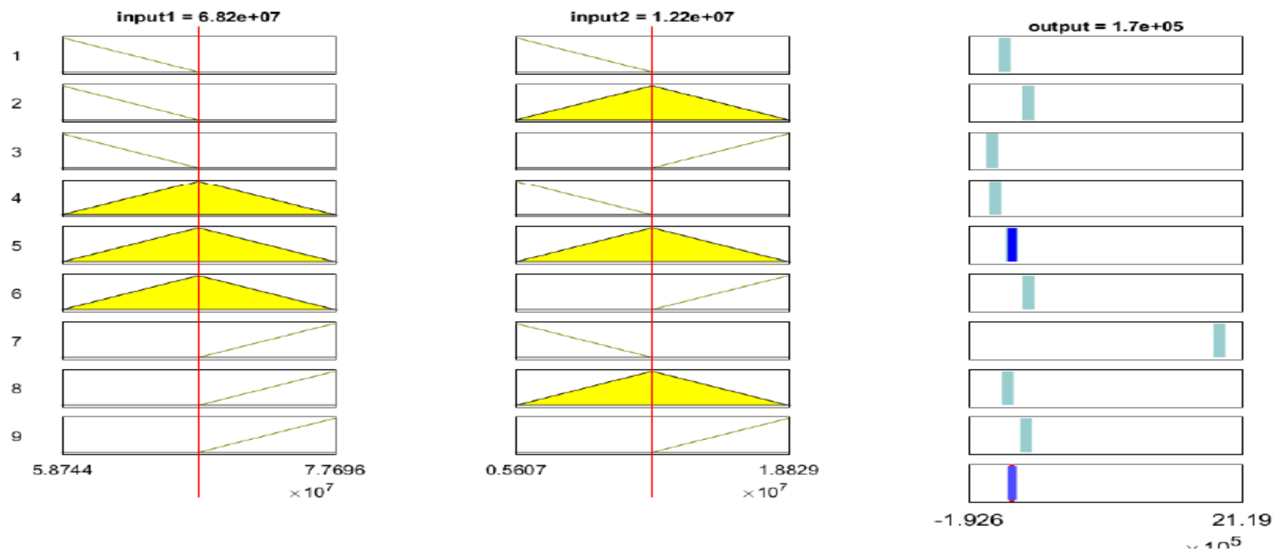


Fig. 5.
Rules Base of Injuries

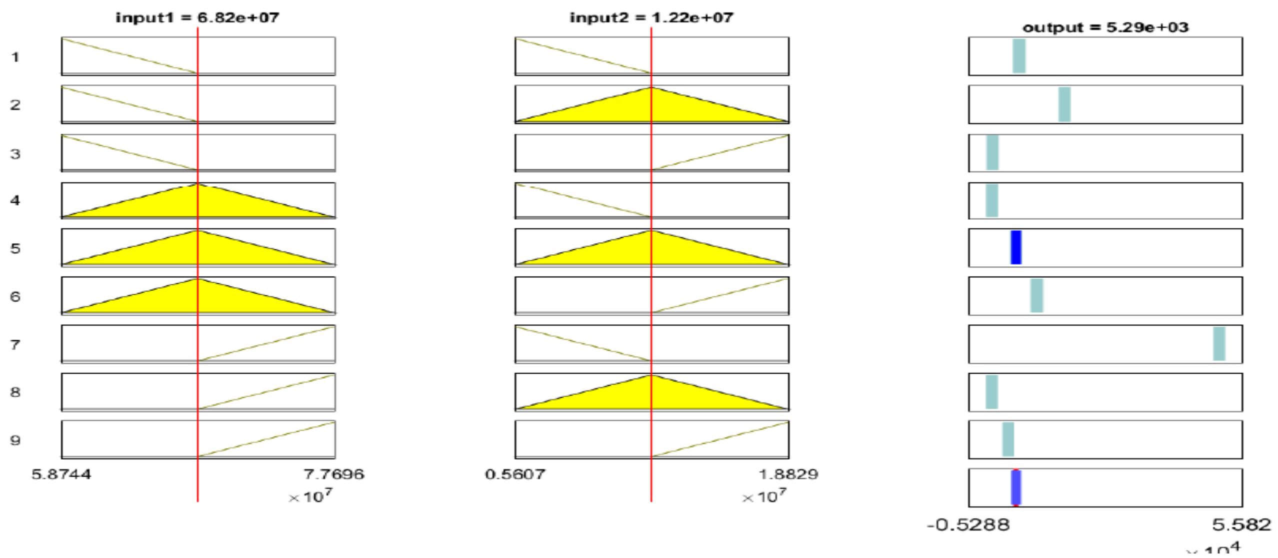
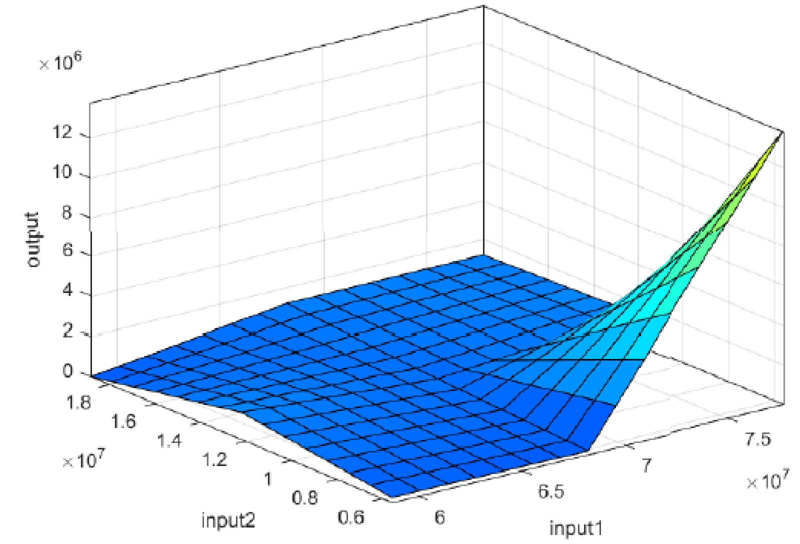
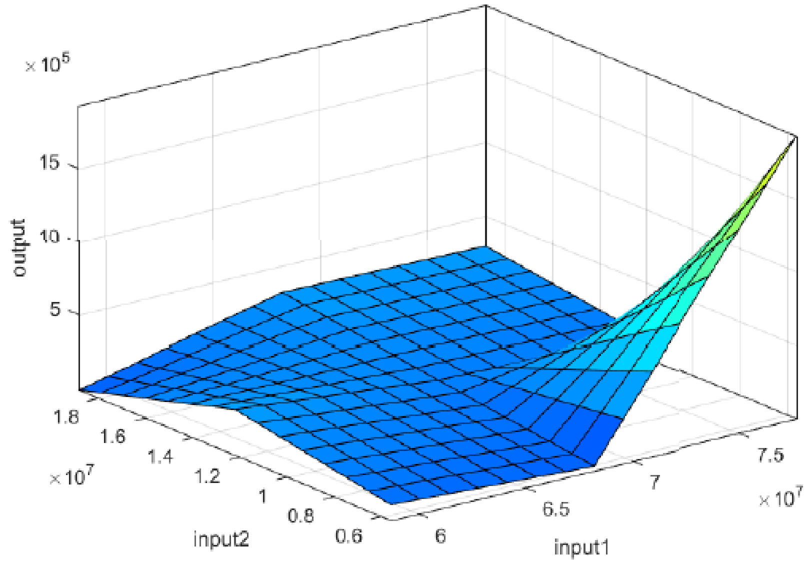


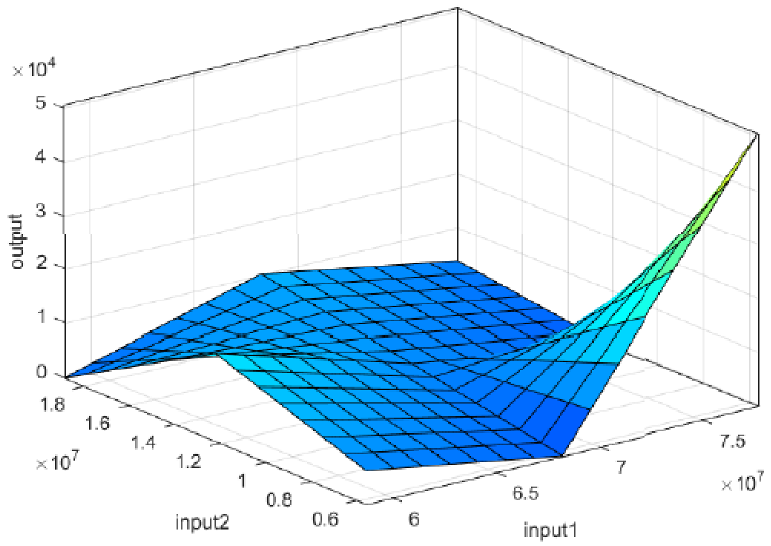
Fig. 6.
Rules Base of Fatalities



a



b



c

Fig. 7.
Distribution of Training Data, (a) Accidents, (b) Injuries, (c) Fatalities

After training of ANFIS, it was tested with test data and obtained estimated values to illustrate the performance of models.

3. Results and Discussion

The performances of models were evaluated in terms of error criteria which are RMSE, MAPE and R^2 defined in Eqs. 1-3.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(D_{Observed} - D_{estimated})^2} \quad (1)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Co_{Observed} - Co_{estimated}}{Co_{Observed}}\right| * 100 \quad (2)$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}(Co_{Observed} - Co_{estimated})^2}{\sum_{i=1}^{n}(Co_{Observed} - Co_{mean})}\right] \quad (3)$$

The comparison results are illustrated in Table 1.

Table 1
The Statistic of Training and Test Data for Comparison

	Accidents		Fatalities		Injuries	
	Training	**Test**	**Training**	**Test**	**Training**	**Test**
RMSE	6595	32825	272	373	4617	8187
MAPE	0.93	4.46	4.24	6.23	2.58	5.23
$\mathbf{R^2}$	0.9996	0.9856	0.8978	0.7428	0.9935	0.9878

Table 2
The Estimated Values of Test Data

Year	Accidents		Injuries		Fatalities	
	Observed	**Estimated**	**Observed**	**Estimated**	**Observed**	**Estimated**
1997	387533	393172	106246	118580	5125	5627
2002	439777	463360	116412	118942	4093	4343
2007	825561	875183	189057	179071	5007	4548
2010	1106201	1141691	211496	214631	4045	3865
2012	1296634	1215584	268079	252994	3750	3811

As seen from Table 1, the R^2 values of all models for training and test are close to each other. Especially, R^2 values of accidents and injuries are better than fatalities. On the other hand, MAPE and RMSE results show that ANFIS performs better for fatalities than the others. Some samples of test data are shown in Table 2. Estimated values of Accidents, Injuries and Fatalities are closer to statistical values. Therefore, in light of these statistical results it could be understood that ANFIS has enough performance and can be used estimation of future values of Accidents, Injuries and Fatalities.

4. Future Estimates of Traffic Accidents, Injuries And Fatalities for Turkey

With the help of developed models, the number of the traffic accidents in the future is estimated, and some measures can be taken to reduce the number of injuries and fatalities by developing new strategies. In this section of the study, a scenario is considered to estimate the number of accidents until 2024. According to the projection of TSI, the population of the country will be around 85 million in 2024. The vehicle ownership rate in Turkey is 0.25 now and it is expected to reach 0.4 by 2024. In this case, the number of the motor vehicles will reach to approximately 34 million.

This rate is consistent with the average vehicle ownership rate in European countries. The reader is referred to Table 3 for data on population and motor vehicle data used in this scenario. ANFIS model estimates are tabulated in Table 4. The study results show that the number of the accident and injuries steadily will increase in Turkey and will reach 2 229 392 and 450 000 respectively. On the other hand, according to the ANFIS model estimate the number of fatalities gradually decrease and will be nearly 2 800.

Table 3
Population and vehicle predictions

Year	Future Estimates	
	Population	**Number of Vehicles**
2015	78 151 750	19 537 938
2016	78 965 645	21 320 724
2017	79 766 012	22 334 483
2018	80 551 266	24 165 380
2019	81 321 569	25 209 686
2020	82 076 788	27 085 340
2021	82 816 250	28 985 688
2022	83 540 076	30 909 828
2023	84 247 088	32 013 893
2024	84 936 010	33 974 404

Table 4
ANFIS model estimates for the number of accident, fatality and injury

Year	Accident Estimates	Injuries Estimates	Fatalities Estimates*
2015	1 349 725	297 288	3 794
2016	1 492 580	317 748	3 684
2017	1 557 985	327 710	3 608
2018	1 694 813	347 586	3 468
2019	1 750 164	357 526	3 437
2020	1 873 752	377 397	3 300
2021	1 989 970	397 260	3 133
2022	2 098 864	417 111	3 005
2023	2 133 063	426 964	2 967
2024	2 229 392	446 766	2 841

*****Deaths in accident locations

5. Conclusion

This study presents an application of the ANFIS to estimate the number of traffic accidents, ınjuries and fatalities in Turkey for the next decade. ANFIS Traffic accident prediction models are developed by using a fifteen-year historical data covering the years between 2000 and 2014. In the model development, the population and number of motor vehicles are considered as model parameters. A comparative study is performed among developed accident models and observed data. The all ANFIS model results have a good agreement with observed data. Moreover while accident and injury ANFIS models catch the increasing trend of traffic accident and injury, the fatality ANFIS model is coherent with decline trend as usual. Therefore, all developed models can be used for future estimates.

All developed models are statistically compared in terms of error criteria, such as RMSE, MAPE and R^2 for both training and test stage. When test statistics are considered the performance of fatality model is relatively better than that of others in terms of RMSE. However, R^2 values of accident and injurie models are better than the coefficient of determination of the fatality model. MAPE values of all developed models are lower than 10%. It means that all models have high accuracy (Lewis, 1982; Lawrence at al. 2009).

In order to evaluate the future performance of the developed ANFIS models, a scenario is considered. This scenario covers a ten year period from 2015 to 2024. According to the scenario, the population and number of vehicles in Turkey will reach nearly 85 and 34 million in 2024, respectively. During the same period the number of accident and injury will steadily increase. While the number of the accident go up from 1 349 725 to 2 229 392, number of the injury raise up from 297 288 to 446 766 if necessary preventions for traffic safety are not taken. On the other hand, fatality ANFIS model results show that the number of fatalities will decrease from 3 794 to 2 841 in the same period.

The performance of a model may increase with increasing the number of the model parameters. However, in this study two common parameters (such as, the number of vehicle and population) are selected for simplicity and practical usage. For further studies, other parameters which are effected on traffic accidents could be employed to improve the performance of the models.

Acknowledgements

The authors would like to thank Republic of Turkey General Directorate of Highways for providing traffic data.

References

Abdel-Aty, M.A.; Radwan, E.A. 2000. Modelling Traffic Accident Occurrence and Involvement, *Accident Analysis and Prevention,* 32(5): 633-642.

Abdelwahab, H.T.; Abdel-Aty, M.A. 2001. Development of Artificial Neural Network Models to Predict Driver Injury Severity in Traffic Accident at Signalized Intersection, *Transportation Reseach Record*, 1746: 6-13.

Ackaah, W.; Salifu, M. 2011. Crash Prediction Model for Two-Lane Rural Highways in the Ashanti Region of Ghana, *IATSS Research,* 35(1): 34-40.

Akgüngör, A.P.; Doğan, E. 2008. Application of Smeed and Andreassen Accident Models for Turkey: Various Scenario Analysis, *Journal of the Faculty of Engineering and Architecture of Gazi University,* 23(4): 821-827.

Akgungor, A.P.; Doğan, E. 2008. Estimating Road accidents of Turkey Based on Regression Analysis and Artificial Neural Network Approach, *Advances in Transportation Studies An International Journal Section A,* 16: 11-22.

Akgungor, A.P.; Dogan, E. 2009. An Artificial Intelligent Approach to Traffic Accident Estimation: Model Development and Application, *Transport,* 24(2): 135-142.

Al-Matawah, J.; Jadaan, K. 2009. Application of Prediction Techniques to Road Safety in Developing Countries, *International Journal of Applied Science and Engineering*, 7(2): 169-175.

Andreassen, D.C. 1985. Linking Deaths with Vehicles and Population, *Traffic Engineering & Control*, 26(11): 547-549.

Chakrobort, S.; Roy, S.K. 2005. Traffic Accident Characteristics of Kolkata, *Transport and Communications Bulletin for Asia and the Pacific,* 74: 75-86.

Chiou, Y.C. 2006. An Artificial Network-based Expert System for Appraisal of Two-car Crash Accidents, *Accident Analysis and Prevention*, 38(4): 777-785.

Codur, M.Y.; Tortum, A. 2015. An Artificial Neural Network Model for Highway Accident Prediction: A Case Study of Erzurum, Turkey, *Promet- Traffic & Transportation*, 27(3): 217-225.

Hosseinpour, M.; Yahaya, A.S.; Ghadiri, S.M.; Prasetijo, J. 2013. Application of Adaptive Neuro-fuzzy Inference System for Road Accident Prediction, *KSCE Journal of Civil Engineering*, 17(7): 1761-1772.

Hosseinlou, M.H.; Sohrabi, M. 2009. Predicting and Identifying Traffic Hot Spots Applying Neuro-Fuzzy Systems in Intercity Roads, *International Journal of Environmental Science & Technology*, 6: 309-314.

Jacobs, G.D.; Hards, W.A.; 1978. Further Research on Accident Rates in Developing Countries, *Report SR434*, Crawthorne, Transport Research Laboratory, UK.

Korkmaz, E.; Akgüngör, A.P.; 2016. An Application of Smeed And Andreassen Accident Models For the City of Ankara by Differential Evolution Algorithm, *International Journal of Soft Computing and Artificial Intelligence*, 4(1).

Lawrence, K.D.; Klimberg, R.K.; Lawrence, S.M. 2009. *Fundamentals of forecasting using excel*, Industrial Press.

Lewis, C.D. 1982. *International and business forecasting methods*. London: Butterworth Scientific.

Mussone, L.; Ferrari, A.; Oneta, M. 1999. An Analysis of Urban Collision Using An Artificial Intelligence Model, *Accident Analysis and Prevention,* 31(8): 705-718.

Russo, F.; Busiello, M.; Dell'Acqua, G. 2014. Road Safety from the Perspective of Driver Gender and Age as Related to the Injury Crash Frequency and Road Scenario, *Traffic Injury Prevention*, 15(1): 25-33.

Russo, F.; Busiello, M.; Dell'Acqua, G. 2016. Safety performance functions for crash severity on undivided rural roads, *Accident Analysis and Prevention*, 93: 75-91.

Smeed, R.J. 1949. Some Statistics Aspects of Road Safety Research, *Journal of the Royal Statistical Society, Series A*, Part I, 1-34.

Turkish Statistical Institute Road Traffic Accident Statistics, 1994-2015. Available from Internet: <www.tuik.gov.tr>.

Valli, P.P. 2005. Road Accident Models for Large Metropolitan Cities of India, *IATSS Research*, 29(1): 57-65.

World Health Organization, Global Plan fort the Decade of Action for Road Safety 2011-2020. Available from Internet: <http://www.who.int/roadsafety/decade_of_action/plan/plan_e nglish.pdf>.

Zegeer, C.V.; Deacon, J.A. 1987. Effect of lane width, shoulder width, and shoulder type on highway safety. In: relationship between safety and key highway features. *State of the Art Report 6, Transportation Research Board,* Washington, D.C., USA.

Zhao, L.; Pawlus, W.; Karimi H.R.; Robbersmyr, K.G. 2014. Data-Based Modeling of Vehicle Crash Using Adaptive Neural-Fuzzy Inference System, *IEEE/ASME Transactions on Mechatronics,* 19(2): 684-696.

SAVE GUIDING OF VISUALLY IMPAIRED PEOPLE - ARTIFICIAL GUIDING LINES ARRANGEMENTS IN THE INFRASTRUCTURE

Jana Košťálová[1], Jaroslav Matuška[2]
[1,2] *University of Pardubice, Jan Perner Transport Faculty, Pardubice, 532 10 Czech Republic*

Abstract: The paper presents arrangements that ensure safe mobility of visually impaired people in public places and sites intended for transport. An analysis of the current situation points to the fact that there is a real problem in using artificial guiding lines as for their parameter differentiation in interior and exterior. Some countries do not use artificial guiding lines at all while others overuse them; moreover, they use different parameters and surface. The article shows how logic is applied in the creation of barrier free environment, where artificial guiding lines are an integral part. Further, the article defines fundamental features and parameters of the artificial guiding lines in the Czech Republic. The aim of the paper is to propose a gradual convergence of tactile arrangement systems, especially for the guiding lines, which are one of the most fundamental requirements for safe mobility of visually impaired people.

Keywords: accessibility, barrier free environment, Design for All, guiding lines, safety, visually impaired people.

1. Introduction

Safety of all pedestrians, not only of the passengers with reduced mobility (PRM), is an important aspect taken into account when assessing the quality of the public environment (Lazou et al., 2015, Susnienė, 2012). Visually impaired people (the blind, the partially sighted) belong among those PRM who need very specific adjustments for their movement. The accessibility of the urban environment, public transport, and other environments is conditioned by specific adjustments that allow the visually impaired to move freely and safely. Independent movement and safety play an important role in the life of the blind and the partially sighted. It is not possible to treat these aspects separately (Matuška, 2009).

To enable the blind to move independently, various technical devices utilising new technologies have been worked on in the last few years. For example Suzuki et al. (2010) conducted an experiment on pedestrian crossings with traffic lights using the assisting technology VLC (visible light communication). He assessed the ability of the blind to maintain straight direction when crossing the road, and their speed. These two parameters affecting the safety of the blind on pedestrian crossings are conditioned by the age of the pedestrians, the time and way of losing their sight (from birth, later in life, suddenly, gradually). Peraković, Periša, and Remenar (2015) showed the possibilities of how to increase mobility and safety of the visually impaired with the help of information and communication technologies. Further, they presented a dynamic model of guiding the blind on an example from the city Zagreb. Periša et al. (2015) investigated the utilisation of the RFID (Radio Frequency Identification) technology for guiding the blind in the urban environment (pedestrian crossings). Zhou et al. (2012) focused on the utilisation of the information & communication technologies enabling easier access of the visually and physically impaired to public transport. Further, Brian et al. (2012) studied the utilisation of modern technologies in the process of guiding the blind in the urban environment. In addition, Kurian and Pillai (2009) conducted research on the system of guiding the blind inside and outside buildings with the help of ultraviolet rays and digital technologies transmitting the information into acoustics.

The blind in the Czech Republic (CR) can make use of a navigation centre, whose staff can monitor the blind via the GPS technology, and when needed the staff can inform him about his position, and tell him the right direction. A research team at the Faculty of Electrical Engineering has been working on the navigation system NaviTerier, designed for mobile phones, which should help the visually impaired in the CR move freely in exterior and interior (Balata et al. (2014).

Despite all the newest devices and assisting technologies, the blind agree that the white cane remains their primary and most easily accessible device for acquiring necessary (tactile) information (Brian et al., 2012; Matuška, 2009). That is why correctly conducted tactile adjustments for the blind are of vital importance. Training of independent movement and spatial orientation with a mobility instructor is a prerequisite for an effective utilisation of the tactile adjustments.

The article aims to explain the logic of the tactile elements (TEs) in the CR and draw attention to the critical points which should be solved consistently and meaningfully.

2. Legal environment

The tactile contrast elements for safe guiding of the blind appeared, for the first time, in the late 70s of the 20th century, in Japan, and from there they spread to Europe (Aoki, Mitani, 2012). The tactile adjustments for the blind are different in each country in terms of law, design, and utilisation. There are states with a large variability of the used tactile surfaces for the same situation, or ambiguously defined requirements for products prevailingly used by the visually impaired (e.g. visual contrasts and slip resistance).

[2] Corresponding author: jaroslav.matuska@upce.cz

2.1. Public transport accessibility

The general terms of the air, rail, bus, and water transport accessibility for the PRM are determined, in the EU, by the relevant regulations. The PRM are guaranteed the right to travel under specified conditions. For example transports or assistance needs requested are subject to advance warning of usually 36-48 hours. This mainly concerns the wheelchair users. The blind people, who do not need any assistance, do not have to report their trip in advance. However, it is impossible to guarantee the given rights throughout the EU as some countries have taken the possibility of exceptions e.g. access to bus terminals.
The general requirements for using the TEs for safe movement and orientation of the visually impaired in transport facilities, in the EU railway system, are a part of the Technical Specifications for Interoperability (TSI PRM, 2014). Unlike the ISO standard, the regulation TSI PRM is applicable only in the EEA[3] countries. Tactile contrast marking must be used for example on platforms and their access paths/roads, on roads leading to check-in halls, or at other places where it is appropriate. The TSI PRM defines the general requirement for using the tactile signs; it does not distinguish between the artificial and natural guiding lines, or other elements.
The railway platform tactile adjustments are, in principal, almost identical throughout the EU. The safety strip at the platform edge (usually 800 mm wide) is separated by tactile and colour contrast adjustments. In some countries (not only in Europe) both surfaces with grooves and blisters are used.
In Great Britain, Loo-Morrey (2005) states six different surfaces with different functions (5 with the warning function and 1 with the guiding function); what more each surface has a precisely defined utilisation (railway platforms, public transport stops, stairs, pavement/ pedestrian crossings, etc.).
In Germany, the basic adjustments for the PRM are conditioned by the standard DIN 18040-3: 2014 or DIN 32984. In Switzerland, the adjustments are conditioned by the regulation SIA 500 or SN 640075. In Slovakia, this issue is addressed in the directive Ondrovič (2011) and Decree No. 532/2002 Coll. The most important decree in the CR is the Decree No. 398/2009 Coll. The Czech Technical Standards (CSN), which deal with specific measures such as at pedestrian crossings, cycle tracks, railway platforms, crossings, and others, build on this decree.

2.2. Accessibility of the built environment

The international standards ISO 23599:2012 and ISO 21542:2011deal with the tactile and visually contrastive adjustments for the blind at building constructions. Both the standards distinguish the attention and guiding patterns. These two patterns are similar to the tactile elements found in European countries. In other TWSIs[4] installation requirements, the adjustments do not fully correspond to the logic of spatial orientation of the visually impaired. The currently set standards for the CR are only provisional as they do not comply with the law and relevant implementing regulations, and technical standards.

3. The logic of tactile adjustments for the visually impaired in the Czech Republic

In a very simple way, visually impaired people can be divided into two groups. The first group comprises the moderate and severely sight impaired people. The second group includes the blind. The ratio of the two groups is, according to WHO[5], 10:1. Each 120th person in the CR is severely visually impaired.
To ensure their independent movement, it is important to transfer the visual information to a combination of TEs. The moderate and severely sight impaired people have different priorities for the combinations. “A sufficient number of easily identifiable points, whose connectors create guiding lines (GLs), forms the basis of safe movement of the blind or partially-sighted” (Dudr, Lněnička, 2002, p. 5). The term ‘*guiding line*’ is prevailingly used when designing barrier-free adjustments for the visually impaired at public facilities, public spaces, and transport environment. The adjustments are those who prevent injuries and loss of spatial orientation, while simultaneously support the targeted transport in exterior and interior. The users of such adjustments are not only temporary and permanently visually impaired people but also people who move through large areas such as transport terminals, or passages of civic facilities because it is difficult to orientate in such places. The fuzzy logic has proved that artificial guiding lines (AGLs) can be intuitively used by people without any visual impairment (Košťálová, 2016). For example, if a user is in a given space for the first time or does not understand the local language or pictograms, his eyes perceive the surroundings more intensively and he intuitively uses the GLs. Therefore, it can be said that GLs are used by a wider range of people than those whom they were originally designed for.
“When walking along a guiding line, it is necessary to keep a 300 - 400 mm safety distance in interior and 800 mm in exterior in order to minimise the risk of crashing into obstacles at the waist level and above” (Slouka et al., 2013, p. 189). A blind person follows the GLs and therefore it is important to maintain a free passage area, which is min. 800 mm wide and 2100 mm high in interior, and 2200 mm in exterior, without any obstacles. This is a fundamental problem of all TWSIs. Not knowing the characteristics of the movement of severely visually impaired people results in placing obstacles in the unobstructed width. The most common examples of such obstacles are promotional items, racks with

[3] European Environment Area
[4] tactile walking surface indicators
[5] World Health Organization

displayed goods, tables and chairs placed freely around the refreshment shops, unsecured scaffolding and excavations, including technical equipment.

3.1. Natural tactile elements forming guiding lines

Natural tactile elements (NTEs) forming guiding lines are created during common construction work or by thoughtful arrangements of the sites; they can assist the blind in terms of orientation and wayfinding. Examples of these NTEs are fence retaining walls, walls of buildings, underpasses, railings with lower guiding bars, garden kerbstones increased by 60 mm above the walking surface. Further, while maintaining the safety principles of guiding the blind, it is possible to use garden adjustments which are increased above the walking surface, palisades, outdoor planter flower pots, and bases of information or ornamental elements, see Fig. 4. Yet, they have to be easily found and identified by a white cane, and must be constant. The legislation of the CR defines these elements as 400 mm wide, 300 mm high, 1500 mm (new buildings) or 1000 mm (reconstructions) long.

3.2. Artificial tactile elements forming guiding lines

An artificial tactile element (ATE) forming a guiding line guides a visually impaired person with a white cane safely at places where another guiding is missing. It is a specially created part of a facility helping the visually impaired to orientate and move independently. After training, a visually impaired person is capable of keeping a straight walking line up to the distance of 8 m, within an acceptable deviation, that is why this distance is incorporated in the Czech standards as a maximal possible interruption of a guiding line.
The basic requirements for TEs in the CR are: min. width 300 mm in interior and 400 mm in exterior, a min. length necessary for directing the visually impaired is 1500 mm at new buildings and 1000 mm at reconstructions, guiding in straight direction, artificial lines cannot be bent, a change in direction is allowed only in necessary situations and preferably at a right angle (90°), crossing of an AGL is done by a flat surface (a paving block without TEs) in the width of the line.
The installation of an artificial guiding line must be logical and simple. The artificial tactile elements forming a GL must be, at both its ends, linked to a natural guiding line or an acoustic guiding device (e.g. an acoustic guiding beacon). Ensuring this continuity is a necessary prerequisite for independent movement of the visually impaired. A continuous line can be formed by visual and TEs or their combination.

3.3. Basic visual elements

A visually contrasting strip, min.150 mm wide, marks the edge of the safety distance at the bus, trolley, and tram stops (500 mm from the edge), is defined by the CSN 73 6425-1:2007. A 150 mm wide yellow strip forms a warning strip and is a part of a GL on level crossing railway platforms. The strip is situated 800 mm from the platform edge, and is defined by the CSN 73 4959:2009, and the Specification of Railway Infrastructure Administration in Ž 8.7, change 2.

3.4. Basic tactile elements

The system of tactile adjustments comprises a combination of basic elements differing in dimensions (effective width) and surface (see Table 1). The products forming the TEs cannot be used for any other purposes. These elements are, in the CR, precisely defined in terms of material, shape and dimensions (see Fig. 4), and must be '*the products*', which comply with the detailed technical and user characteristics defined by the Technical Centre TN TZUS 12.03.04-07. Each element must have a product verification complying with the Government Decree No.163/2002 Coll. The material used, in the CR, is not innovative; mostly, it is concrete or stone paving blocks, or stone blocks forming a mosaic. Paving blocks from artificial stone, polymer concrete slabs or plastic belts (rubber, recycled material, PVC) are used to a limited extent.

Table 1
Basic Tactile Elements

SURFACE	**WIDTH** [mm]	**FUNCTION**
BLISTERS *according to the material used walking areas: truncated cones or hemispherical pins, irregular stumps*	150	warning
	400	warning
	800 - 1000	directing, orientation important point
LONGITUDINAL GROOVES *cross sections of grooves: a sinusoidal rib, a triangle, a rectangle, or a trapezoid*	300 inter. / 400 ext.	guiding – walking area for pedestrians
	550	guiding – vehicular way

Source: Decree No. 398/2009 Coll.

Important visual information for the blind has to be transferred to tactile or acoustic information. The requirement is also applied to road signs, where the combination of basic elements signals a change in the traffic mode and differentiation of the function groups on the roads; e.g. the differentiation between a pavement and a cycle track or the differentiation between pedestrian and residential areas and the roads (see Fig. 4).
The sequence of adjustments in parts of buildings, roads and public places for the visually impaired:

- the priority is to organise the disposition of a sufficient number of appropriate (and clear) orientation points and NTEs forming GLs,
- it is important to utilise the acoustic guiding and visual contrasts to improve the orientation situation, (see Fig. 1)
- an AGL is used only as a complementing element (interior and exterior) for ensuring independent movement.

All the elements must be perceptible by a white cane and sole while maintaining the visual and tactile contrast.
The surface area, at a minimal distance of 250 mm from the elements, must be flat and in compliance with the slip resistance requirement. To ensure the tactile requirement, it is necessary to design the paving without any skews, and with a straight edge, which does not create any gaps noticeable by a white cane (see Fig. 2, 3).

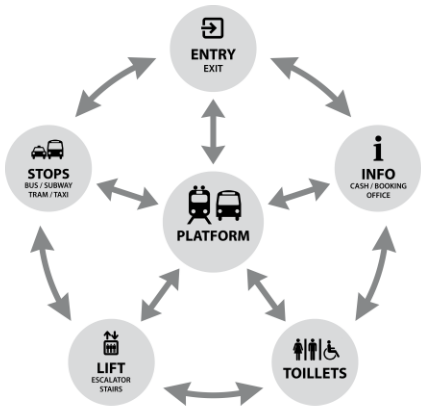


Fig. 1.
Accessibility Scheme
Source: J. Košťálová

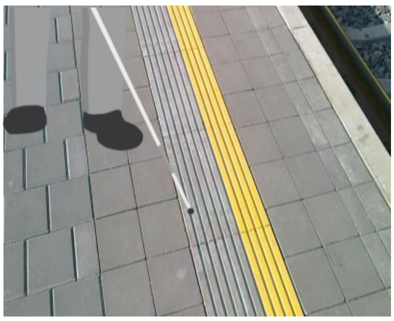


Fig. 2.
Resolving TE in the concrete pavement – railway platform
Source: P. Lněnička

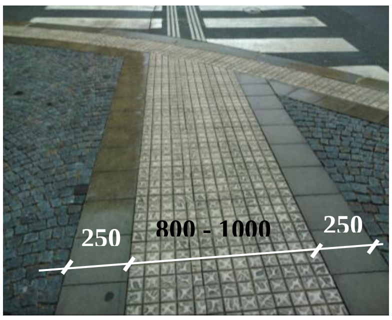


Fig. 3.
Resolving TE in granite paving - pedestrian crossing
Source: J. Košťálová

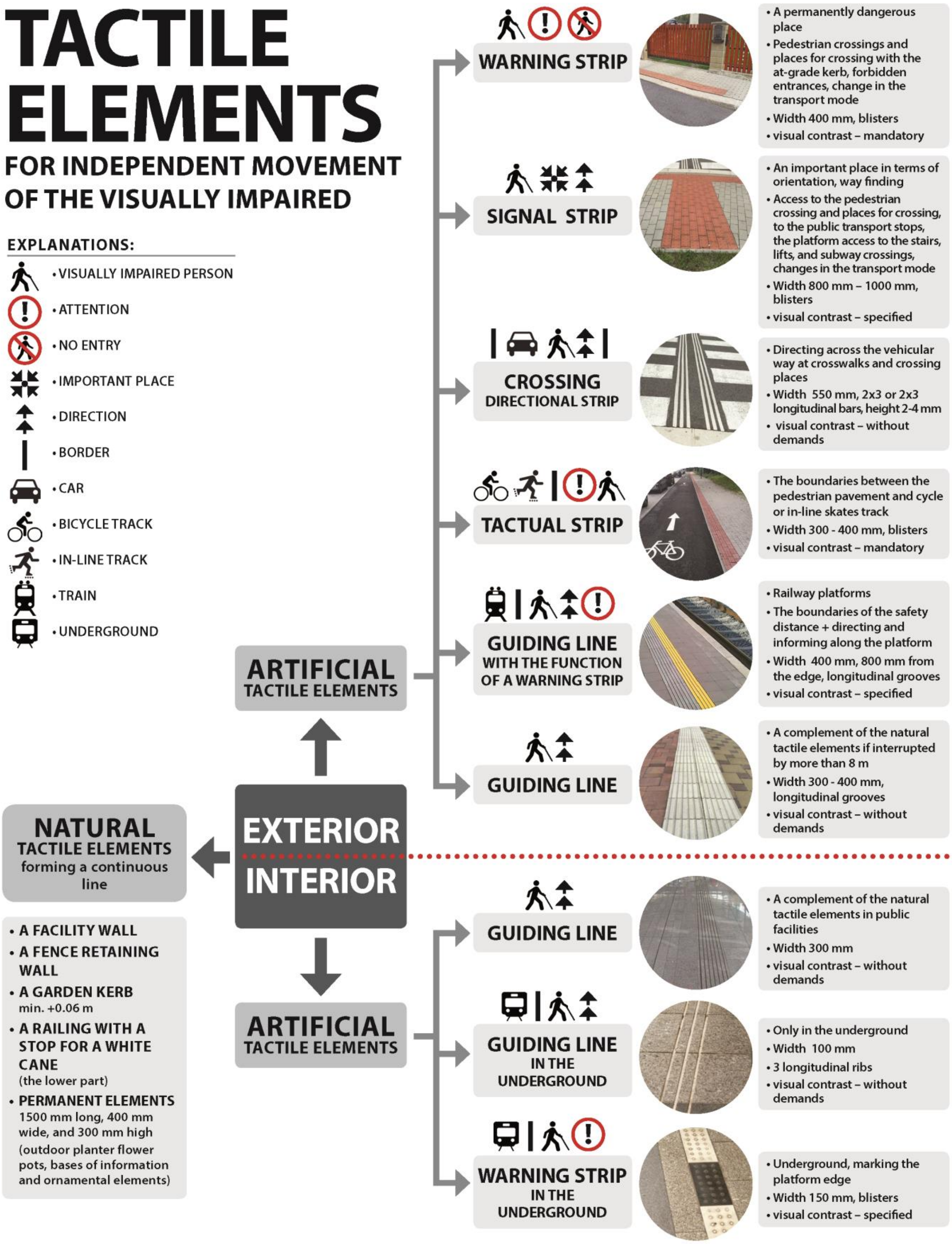
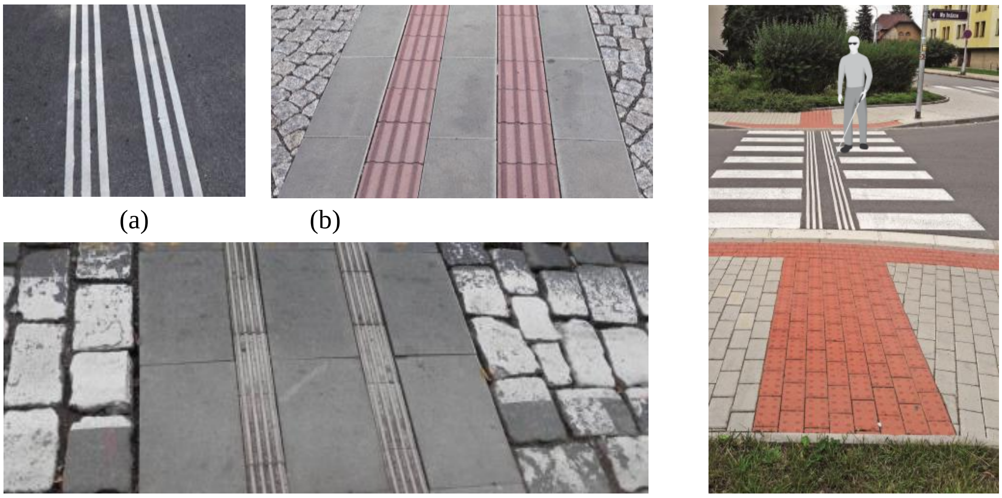


Fig. 4.
Tactile Elements in the CR
Source: Author J. Košťálová

4. Differences between the Czech Republic and other countries

The analysis of the current situation in safe guiding of the blind indicates that:

- The majority of European countries currently use AGL and TE made of a wide range of **material**. Stone or concrete tactile paving is the most widely used but ceramic tiles and PVC belts, products from polymer concrete, and stainless steel are also used; e.g. in Slovakia (Ondrovič, 2011), and in Poland (Poliński, 2013).
- The standard ISO 21542, similarly to some other transnational regulations (e.g. the TSI PRM), defines the **colour contrast of the elements**; this is not included in the Czech legislation. The standard describes a simple method of light reflectance value difference, and, for a comparison, other three methods widely used in the world (Michelson, Weber, Sapolinski). When defining the necessary colour contrast, it is important to take into account the character of the displayed information (orientation or safety).
- A rarely used TE in Europe is the **crossing directional strip** in a vehicular way, which helps to shorten the time in dangerous places, see Fig. 5 (d). In the CR, it is only installed at pedestrian crossings, where it is difficult to keep the direction: the signal strip is not long enough (< 1 m), the axis of the crossing is not perpendicular to the axis of the road and its length is longer than 8 m, or the crossing comes from the rounded curbs of *r* > 12 m in diameter. It is necessary to maintain the colour contrast depending on the material used, see Fig. 5(a) – (c).



(a) (b)

(c) (d)

Fig. 5.
Crossing Directional Strip
Source: J. Košťálová

- **Surface structures** are unfamiliar with the negative relief (groove in the surface), which is commonly used in the CR. Such structure is used for guiding the blind on platforms, or inside terminals.
- Research in V4 countries has proved that **acoustic information** is important for the visually impaired, yet insufficiently used (Matuška et al., 2015).
- A wide variety of **guiding patterns** is used for the same situations, which are difficult for the blind to remember (one bar, two bars, two triples of bars, paving with 5-7 grooves, a combination of a negative relief[6] and steel guiding riband).[7]
- **Tactile elements** with an attention pattern are not used in the CR in front of sloping barrier-free ramps and stairs as the visually impaired are guided by the AGL, from the side, to the railing. No tactile element should create an obstacle for other users (people in wheelchairs, people with physical disabilities and small children) when entering and leaving the ramps, see Fig. 6. According to the Czech Statistical Office, there are, in the CR, six times more people with severe physical disabilities than visual.
- In the subways, malls, corridors, the TEs are often situated in the centre of the walking area and they do not respect the usable lines of the walls. Should the load increase, the elements rising above the surface have reduced durability and create obstacles, see Fig. 7.

[6] milled grooves
[7] e.g. on the platform in Warszawa Centralna

Fig. 6.
TE before a ramp
Source: J. Matuška

Fig. 7.
Additional adjustments in Udine, Italy
Source: J. Matuška

5. Conclusions and recommendation

The function of individual elements (different according to the national standards) must not be confusing, as the user safety is the priority. The legislation of most European countries addresses these requirements, yet the reality shows the more the information and details have to be solved additionally, the more incorrect and life-threating the situations. Instead of a simple functional solution, the result is incomprehensible for severely visually impaired people and causes restrictions for other users.

NTEs used in interior or on roads are advantageous for:

- **the blind -** as they get permanent information, which is more recognisable by the white cane and is less dependent on the weather and pollution,
- **investors** – NTEs save financial means spent on adjustments for safe guiding of the blind, allow easier cleaning and maintenance of the walking areas,
- **other users** of the environment – NTEs do not create any obstacles (for small children, people in wheelchairs, people with rollators, crutches, or sticks, etc.).

The process of creating a barrier - free environment (user-friendly) has to take into account not only the legislation (design and planning) but also the finances. Long-term sustainability can only take place in the cities with smart municipal politics, with cost-effective and accessible public transport and the modification of its conception; further, with the education of the experts forming the public environment (transport and building civil engineers, architects, representatives of governments and legislators).
Some good examples are not only seen in some European cities, Japan, the USA and Canada, but also in some cities in South America. Therefore, it is necessary to pay attention to all the TEs forming tactile GLs, which are and will be a necessary part of Design for All.
Experts including the members of the European Blind Union should discuss the following topics: effects of the increased use of NGLs in interior and exterior; materials suitable for guiding the blind in interior and exterior; the unification of basic adjustments for the blind across Europe; the use of acoustic information for the blind.

Abbreviations used:

AGL:	*artificial guiding line*
ATE:	*artificial tactile element*
CR:	*Czech Republic*
CSN:	*Czech Technical Standard*
GL:	*guiding line*
NGL:	*natural guiding line*
NTE:	*natural tactile element*
PRM:	*passengers with reduced mobility*
TE:	*tactile element*
TSI PRM:	*Technical Specifications for Interoperability passengers with reduced mobility*
TWSI:	*tactile walking surface indicators*

References

Aoki, H.; Mitani, S. 2012. Tactile walking surface indicators. Making streets safer for visually impaired pedestrians. ISO Focus. Special Report TC 173.

Balata J.; Franc J.; Mikovec Z.; Slavik P. 2014. Collaborative Navigation of Visually Impaired, *International Journal on Multimodal User Interfaces*, 8(2): 175-185.

Commission Regulation (EU) No 1300/2014 of 18 November 2014 on the technical specifications for interoperability relating to accessibility of the Union's rail system for persons with disabilities and persons with reduced mobility.

Decree No. 398/2009 Coll. The general technical requirements ensuring barrier-free use of buildings.

Dudr, V.; Lněnička, P. 2002. *Designing constructions for safe and independent movement of visually impaired people*. Recommended technical standard, 5/11. Praha: IC ČKAIT, 72 p.

ISO 21542:2011. Building construction - Accessibility and usability of the built environment.

ISO 23599:2012. Assistive products for blind and vision-impaired persons - Tactile walking surface indicators.

Košťálová, J. 2016: Fuzzy logic for the use of artificial guiding lines. Unpublished part of a dissertation. University of Pardubice, 25 p.

Lazou, O.; Sakellariou, A.; Basbas, S.; Paschalidis, E.; Politis, I. 2015. Assessment of LOS at pedestrian streets and qualitative factors. A pedestrians' perception approach. In *Proceedings of 7th International Congress on Transportation Research*.

Loo-Morrey, M. 2005. Tactile Paving Survey. Report Number HSL 2005/07.

Matuška, J. 2009. *Barrier-Free Transportation*. Pardubice: Institut of Jan Perner, 2009. 196 p.

Matuška et al. 2015. Rights of passengers with reduced mobility in Visegrad 4 countries. Project Nr. IVF 11420036. Pardubice, Warszawa, Budapest, Žilina. 2015.

Ondrovič, M. 2011. Technical Specifications TP 10 /2011. Designing accessible arrangements on ground communications for people with reduced mobility. Ministry of Transport, Construction, and Regional Development SR.

Periša, M.; Peraković, D.; Vaculík, J. 2015. Adaptive technologies for the blind and visual impaired persons in the traffic network, *Transport*, 30(3): 247-252.

Poliński, J. 2013. Tactile information for blind and visually impaired people. Part II – Tactile paths, *Railway issues*, 158: 19-34.

Slouka, I. a kol. 2013: *Teaching spatial orientation to visually impaired people: methodological handbook*. Brno : Tribun EU s.r.o. 2013. 209 p.

Susnienė, D. 2012. Quality approach to the sustainability of public transport, *Transport*, 27(1): 102-110.

Suzuki, K.; Fujita, M.; Watanabe, Y.; Fukuzono, K. 2010. Performance evaluation of a crossing-assistance system for visually disabled persons at intersections considering actual road structure, *International Journal of Intelligent Transportation Systems Research*, 8(1): 26-35.

Zhou, H.; Hou, K.-M.; Zuo, D.; Li, J. 2012. Intelligent Urban Public Transportation for Accessibility Dedicated to People with Disabilities. *Sensors* 2012, 12: 10678-10692; doi:10.3390/s120810678.

ANALYSIS OF DRIVERS CONDUCT WHILE DRIVING OVER THREE DIFFERENT PEDESTRIAN CROSSINGS BY USING EYETRACKING METHOD

Pavel Maxera[1], Michal Belák[2], Robert Kledus[3], Marek Semela[4], Kateřina Bucsuházy[5], Veronika Svozilová[6]
[1,2,3,4,5] *Institute of Forensic Engineering, Brno University of Technology, Brno, Czech Republic*
[6] *Faculty of Electrical Engineering and Communication, Brno University of Technology, Brno, Czech Republic*

Abstract: The Study analyses the conduct of several drivers while driving over three different type of pedestrian crossings by night. The monitored vehicle drives over horizontally and vertically marked pedestrian crossings in a town. These pedestrian crossing have different structural arrangements and different location. The first and the second of them are standard type of pedestrian crossing and the third is modern type with the traffic island. Abilities of driver's perception have been influenced by the not quite suitable crosswalk arrangements as well as by unnoticed surroundings near the crosswalks. The results of the analysis have been compared to the results of extensive driving tests conducted in real road traffic, in the year of 2014. Optical reactions of drivers have been measured by using eyetracking method. Changes in the driver's perspective have been measured by using a special eyetracking device called Viewpointsystem®, GmbH from Austria. The driver's conduct in definite traffic scenarios, driver's reaction to crossing pedestrians, driver's watching duration of crossing pedestrians, controlling of the situation behind the vehicle by the driver using the rear-view and outside mirrors (i.e. total necessary time for the driver to assess the situation behind the vehicle as well as individual parts of entire time) as well as driver's reaction to another significant stimulus have been evaluated. The vehicle operating by the driver has been monitored using sensors in the vehicle.

Keywords: road traffic safety, traffic accidents involving pedestrians, driver's optical reaction, controlling of the situation behind the vehicle, collision prevention option, eye movement monitoring.

1. Introduction

Pedestrians belong among the most vulnerable road traffic participants. In the Czech Republic alone 131 pedestrians died as a result of traffic pedestrian-vehicle accidents in 2015 (which is around 19 more than in 2014). 128 pedestrians were mortally wounded in vehicle collisions, while the remaining three were secondary accident participants. The majority (more than 56 %) of pedestrians, who died as a result of collision with vehicles, were mortally wounded at night (72 of 128 people, which is about seven more than in 2014) (CSPSD, 2015).
Light conditions have a significant impact on the increased danger at night. These light conditions significantly affect not only the ability of a driver to recognize a pedestrian in time, but also the ability of a pedestrian to identify the vehicle's position and speed. The ability of a driver to recognize a pedestrian is further affected by the complexity of a driving situation. The more and more stimuli, the higher the probability that a driver will not notice one of the important ones. The number of stimuli also increases when vehicles drive consecutively. In such a case a driver has to pay more attention to traffic behind the vehicle with the help of rear view mirrors. One of the important factors is therefore the time needed for the investigation of the situation behind the vehicle. Pedestrian crossings are frequent sites of traffic accidents. According to Czech Police statistics, accidents most often occur as a result of inattentive or unexpected entry of a pedestrian into the road. It is necessary to pay a constant attention to the safety of pedestrians and strive for the extension of knowledge about driver's perceptional viewing of the driving situation and his behaviour in areas with increased danger, because pedestrians are very vulnerable participants of road traffic.

2. Analysis of the contemporary situation

The contemporary development of measurement methods based on so-called eyetracking (measurement of the change in the angle of driver's view) enables the extension of knowledge about a driver's behaviour during the driving process. Viewpointsystem® instruments, besides other things, achieve highly accurate measurements. Some of them even enable measurement at night under ordinary road traffic conditions. By this method it is possible thereafter to acquire new knowledge about a driver's perception of the driving situation, a driver's response to various stimuli, a driver's behaviour during the driving process, and also about his ability to distinguish important driving stimuli at an adequate distance, and subsequently investigate the influence of a driver's surroundings at this distance. In his works (Pfleger, 2012; Pfleger, 2009; Pfleger, 2010; Pfleger, 2013), Pfleger – the author of Viewpointsystem® method – deals with the investigation of a driver's behaviour, in particular driving situations and his complex analysis, on a long-term basis. Many research works deal with, thereafter, an analysis of drivers' response time to various stimuli and the influence on its length by light conditions and other factors. Some aspects of modern methods and procedures in research of perceptual recognition of pedestrians are introduced by Weyde (Weyde, 2010). Habibovic et al. (Habibovic, 2013) analyses, on the basis of videos recorded from the vehicle, different driving situations, during which a pedestrian crosses the road from various directions. He adjusts the DREAM method (The Driving Reliability and Error Analysis Method) for the identification of the factors affecting a driver's attention, direction of his view, and a pedestrian's

[1] Corresponding author: pavelmaxera@gmail.com

behaviour while crossing. The ways leading to the creation of a safe and user-friendly environment on different types of roads are introduced by Mackie (Mackie, 2013) in his work. On the basis of the implementation of a proposal of changes he points to the ways that favourably influence the conduct of road traffic participants. Bella and Silvestri (Bella, 2015) dealt with possibilities of increasing safety at pedestrian crossings situated on two-lane urban roads. They carried out measurements using a modern driving simulator, where they simulated various driving situations and examined the influence of safety features (extension of kerbs, restriction of parking near a pedestrian crossing, deceleration retardants) on a driver's behaviour. Ni et al. (Ni, 2016) dealt with an analysis of the movement of vehicles and pedestrians at pedestrian crossings and the detection of critical situations from camera records. They evaluated the mutual movement of vehicles turning right and pedestrians passing over a pedestrian crossing in relation to the time and speed of individual traffic participants. Sullivan (Sullivan, 2011) points out, proceeding from the evaluation of police investigation reports about traffic accidents with pedestrians, differences in the course of these accidents at daytime and at night. He calls attention to the influence of symmetrical and asymmetrical headlights on the ability to see a pedestrian. Jurecki and Stańczyk (Jurecki, 2014) dealt with the time of a driver's response to a pedestrian entering the road from its right and left side. In simulated driving situations they analysed the movement of a vehicle from the moment of optical stimulus creation to the vehicle stop. They situated screens on both sides of the road, subsequently placed figures behind them and at a certain moment exposed them to the drivers. The task of the drivers was to respond to the change of the driving situation by means of activation of the vehicle braking system and stopping the vehicle by braking. The driver's response time was measured. Even the authors of this publication dealt with the issue of a driver's behaviour during the driving process in reduced visibility by darkness in an area of pedestrian crossings. In the work (Kledus, 2013) they examined the driver's behaviour at a pedestrian crossing designed in a modern way. In the work (Maxera, 2015) they dealt with the driver's behaviour when passing through a common pedestrian crossing in an area with many stimuli caused by the nearness of other crossings and a number of road signs. The time that a driver needs to evaluate the situation behind a vehicle was analysed in the article (Belák, 2016). This article follows the authors' previous works and those works further develops this.

3. Aims of the work

The aim of the work is to compare behaviour of 20 drivers in an area of three pedestrian crossings designed in various ways. It attempts to verify, proceeding from the comparison, the appropriateness of the K coefficient in quantification of danger in the area of a pedestrian crossing under various conditions. It further aims to compare the values of characteristic quantities describing the behaviour of the driver and pedestrian in different driving situations laid down by the different ways in which the pedestrian crossings are designed. It mainly attempts to evaluate the time of driver's response in relation to hazardousness of the situation and also the degree of attention the driver pays to the pedestrian from the moment of noticing the stimulus by eye retina (or from the moment of the first optical reaction, hereinafter FOR) to the moment at which a vehicle passes over the crossing. Attention is also paid to the time that the driver devotes to observation of the situation behind the vehicle while passing over the crossing.

4. Methods of solution

4.1. The method of performance of driving tests

The performed evaluations proceed from extensive driving tests carried out in 2014. Measurements were made within a solution of TAČR TD 02239 project – Strengthening of legal certainty in technical evaluation of traffic accidents with pedestrians in reduced visibility. The tests were performed under ordinary road traffic conditions. Drivers' behaviour in reaction to analogous driving situations was monitored during testing. Experienced drivers passed through a given trajectory at a distance of ca. 23 km in an ordinary way. There were figures placed on the route that simulated the same driving situations. The presented evaluations show the results achieved at three pedestrian crossings, where the figures simulated passing pedestrians.

4.2. Measurement technology and vehicles

For measurement two comparable vehicles of Škoda Yeti, Czech made brand have been used. The first vehicle was equipped with headlights containing halogen bulbs, while the second one was equipped with headlights containing xenon discharge tubes. Because of the fact that all presented measurements were carried out on stretches of a road with public illumination, the differences in headlight properties are not crucial for evaluation of the tests as they do not become significantly evident when the road illumination is sufficient. The vehicles were equipped with measurement technology according to Table 1. Viewpointsystem® measuring device was used for the measurement of a vision angle direction. Its main part is formed by rims in the shape of glasses with two cameras. The first part scans the driver's eye lens, while the second part scans the situation in direction of the driver's view. The view direction is evaluated from a comparison of records of both cameras using specialized software. The position of the vehicle and movement of its bodywork during testing were measured with the help of an accurate, differential GPS. The way of the driver's vehicle control was further evaluated with the help of data acquired from sensors used for the vehicle drive unit (OBD diagnostics) and from a sensor of the brake pedal position.

Table 1
Survey of used measuring devices and measured quantities

Measuring device	Measured quantities
Eyetracker (Viewpointsystem®)	Direction of a vision angle of the driver
GPS device	Vehicle trajectory, angles of pitch, incline, bodywork turn
OBD Diagnostics (On-Board Diagnostics)	Engine speed, vehicle speed, rate of accelerator press
Infra LED diode connected with the braking pedal position sensor	Braking pedal activation moment

4.3. Measurement areas and figures

For measurement three pedestrian crossings designed in various ways were chosen. All of them were marked with horizontal and vertical traffic signs and illuminated by means of public illumination lamps situated in the driving direction of the vehicle on the right side. The first crossing (CW1) was situated on a straight road stretch near a car park exit. On the sides in the area of side guide lines and in the middle in the area of a central dividing line circular decelerating retardants were situated. However, these retardants do not limit significantly the passing of smaller vehicles. The second crossing (CW2) was situated nearby a left turn on a clear stretch of main road. The crossing was designed in a modern way, with a central dividing traffic island and yellow retroreflective framing of signs highlighting the crossing sign. The third crossing (CW3) was situated at the end of a straight, relatively indented stretch of road with three more crossings and numerous traffic signs. In the right direction of the driving vehicle there was a park with full-grown trees in the area of the crossing. The trees limited the view of the areas adjacent to the road in the area of measurement. A comparison of monitored crossings is performed in Fig. 1.

Fig. 1.
Areas of measurement – CW1 crossing (on the left), CW2 crossing (in the middle), CW3 crossing (on the right)
Source: (Google Maps, 2016)

All three figurants had darker clothes of various colours. At the crossings CW1 and CW3 both figurants wore a black jacket, dark denim trousers and black shoes. Figurant at the CW2 crossing had a black jacket, red trousers and dark shoes. The figurants' clothes was compared in Fig. 2. The figurants were waiting near the crossing in the right direction of the vehicle pass during driving tests. At the moment of arrival of the testing vehicle they were supposed to cross the road in the ordinary way before the passing vehicle in order not to endanger themselves.

Fig. 2.
Figurants at posts before entrance to the road - CW1 crossing (on the left), CW2 crossing (in the middle), CW3 crossing (on the right)

4.4. Result processing method

A driver's eyes respond to visually significant stimuli, which are also pedestrians moving on the road and in its proximity, by instant involuntary change in the direction of a vision angle in such a way that the stimulus can be observed in the area of sharp vision of an eye and subsequently analysed in the central nervous system, see Fig. 3. In the case where this change in the vision angle is evident, it is possible to evaluate with high credibility the beginning of FOR to a given stimulus. On the basis of an analysis of saccadic and smooth monitoring movement of eyes it is thereafter possible to evaluate not only the moments of FOR to individual stimuli, but also a time that the driver pays attention to the pedestrian passing over the crossing or even to other important stimuli including those observed by the driver using rear view mirrors.

Fig. 3.
Example of the first optical response of the driver to the pedestrian (drive P12 crossing CW2; on the left – the beginning of the optical reaction (8.56 sec and 66.4 m prior to the crossing), the driver's eye when looking in a straight direction peripherally notices the figurant; on the right side – figurant in the area of sharp vision (8.52 sec and 65.9 m prior to the crossing), the driver's eye after change in view direction fixes on the figurant.

4.5. Result processing procedure

The way of driving of 20 drivers was evaluated at each of the monitored pedestrian crossings. The characteristics listed below describing a driver's behaviour and the mutual movement of the vehicle and passing figurant were discovered for each driving process:

1. The point of intersection of a vehicle trajectory and a figurant trajectory was determined in the area of the crossing. This place was chosen as the beginning of the coordinate system for measurement of distances s between the vehicle and the crossing. The direction against the vehicle driving direction was chosen as positive. In the point of intersection it is therefore true $s_{CRW} = s = 0$.
2. The moment of vehicle pass over the pedestrian crossing was determined t_{CRW} and instant vehicle speed v_{CRW} when passing the crossing. For further result processing the time t_{crw} was chosen as the moment equal to time 0 ($t_{CRW} = t = 0$). In the case that the driving situation required the driver to stop the vehicle prior to the crossing, the moment of vehicle stop was determined. This moment was subsequently chosen as the moment equal to the time 0.
3. The moment of the first optical response (FOR) of the driver to the passing figurant was chosen t_{FOR} and vehicle distance from the crossing equal to this moment s_{FOR} and instant vehicle speed v_{FOR}.
4. The moment of acceleration pedal release by the driver was determined t_{RAP}, or also the moment of breaking pedal activation by the driver t_{ABP}. At the same time the response times from the FOR moment were calculated according to relationships $\Delta t_{RAP} = t_{FOR} - t_{RAP}$ and $\Delta t_{ABP} = t_{FOR} - t_{ABP}$.
5. The substantial moments related to the movement of the figurant around the road and on the road were determined. It was always the moment of entrance of the figurant to the road t_1 and the moment, when the figurant left the traffic lane, in which the monitored vehicle was moving t_2. The quantities characterizing the vehicle movement in these moments, i.e. a distance between the vehicle and the crossing s_1, s_2 and instant vehicle speed v_1, v_2, were subsequently determined.
6. The degree of attention *Att* that the driver paid to the figurant from the FOR moment to the pass of the vehicle over the crossing was evaluated. The relative value was expressed as a percentage according to relationship $Att = \sum \Delta t_{att} \cdot 100 / t_{FOR}$,where $\sum \Delta t_{att}$ is the sum of the time intervals, in which the driver watches the figurant in the area of sharp view of the eye and t_{FOR} determines the time interval from the FOR moment to the moment of vehicle pass over the crossing.
7. The time Δt_{PR} that the driver after noticing the figurant controlled the situation behind the vehicle by means of the rear view mirror, or the time Δt_{PO} that he devoted to control of the situation behind the vehicle after passing over the crossing, was evaluated.

8. On the basis of the evaluation of vehicle speed v_{FOR} in the FOR moment the minimum value s_{BRK}, necessary for stopping the vehicle from v_{FOR} speed, was subsequently calculated[2]. On the basis of comparison of distances s_{FOR} and s_{BRK} the value of dimensionless coefficient **K** was subsequently stated for each drive according to relationship $K = s_{FOR}/s_{BRK}$, which characterizes in an appropriate way the hazardousness of the emerged driving situation. The K coefficient values lower than 1 mean that in case the figurant started the crossing process during a given test, the driver would not probably stop prior to the crossing and the collision of the vehicle with figurant would possibly take place.

The drives were divided into four basic categories according to the K coefficient values:

1. Entirely safe drives ($K > 2.5$) – during these drives the drivers optically responded to the figurant at a sufficient distance and the driving situation thus did not require immediate action of the driver, such as immediate accelerating pedal release or even the activation of the brake pedal. The driver thus only decelerated vehicle speed in the ordinary way and the figurant crossed the road without any problems (the drives are depicted by green colour on the charts on the Fig. 4 – 6).
2. Drives with increased danger ($2.5 \geq K > 1$) **-** during these drives the drivers optically responded to the figurant later than in category 1, often immediately after FOR adjusted the vehicle drive, decelerated intensively, but did not need to stop the vehicle prior the crossing (the drives are depicted by red colour on the charts on the Fig. 4 – 6).
3. Dangerous drives ($2.5 \geq K > 1$) – during these drives the drivers optically responded to the figurant later than in category 1, immediately after FOR adjusted the vehicle drive and had to apply the brakes until the vehicle stopped so the figurant could cross the road (the drives are depicted by red colour on the charts on the Fig. 4 – 6)
4. Critical drives (usually $K \leq 1$) – during these drives the drivers optically responded to the figurant too late, or not at all and the figurant evaluated the situation as very dangerous and did not even initiate the process of crossing the road (the drives are depicted by grey colour on the charts on the Fig. 4 – 6).

5. Presentation of results

5.1. Evaluation of measurement on the CW1 crossing

The results of measurement on the CW1 crossing and the performed evaluations are graphically compared on the Fig. 4. Individual drives are distinguished by colours according to the above mentioned categories (entirely safe drives, drives with increased danger, dangerous drives and critical drives). They are sorted by the determined values of K coefficient. From the charts in Fig. 4 it is clear that 14 out of the 20 drivers managed to respond to figurant at a sufficient distance and in many cases did not even need to activate the brake pedal ($K > 2.5$), five drivers had to brake intensively, although they did not need to stop the vehicle prior to the crossing. None of the drivers had to apply the brakes until a stop. Only one driver reacted too late ($K = 0.88$). In this case the figurant evaluated in the right way the possible danger and did not even enter the road. The moments of the first optical reactions of the drivers, the moments of acceleration pedal release, brake pedal activation and the corresponding distances between the vehicle and the crossing can be subtracted from the charts in Fig. 4.

The average values of characteristic quantities including the lengths of reaction times and proportional observation times of the figurant by the drivers are stated in Table 2. From observation of the test, during which the figurant was crossing the road, it is clear that the average time from the FOR moment until the moment of vehicle pass over the crossing was 8.0 s. During this time the drivers directly observed the figurant for an average time of 4.9 s, which is 61 % of the time they had at their disposal. They paid him the most attention at the time before the entrance to the road and during the movement in the right traffic lane. The average time of observation of the figurant before the entrance to the road was 2.3 s, which is 86 % of the time 2.7 s that the drivers had at their disposal. In the right traffic lane, the figurant was moving for on average 2.5 s. During this time the drivers were directly watching him for on average 1.9 s, which is 76 % of the time they had at their disposal.

In the monitored stretch only seven drivers controlled continuously the situation behind the vehicle, while ten drivers did not use rear view mirrors. Only one driver controlled the situation behind the vehicle during deceleration process, four drivers controlled the situation behind the vehicle immediately after passing over the crossing. The determined times needed for control of the situation behind a vehicle with the differentiation of the time of the actual scene fixation in the rear view mirror are stated in Table 3.

[2] A reaction time of the driver of 1 sec and achievable deceleration of the vehicle 5.8 m/s^2 are taken in account in the calculation.

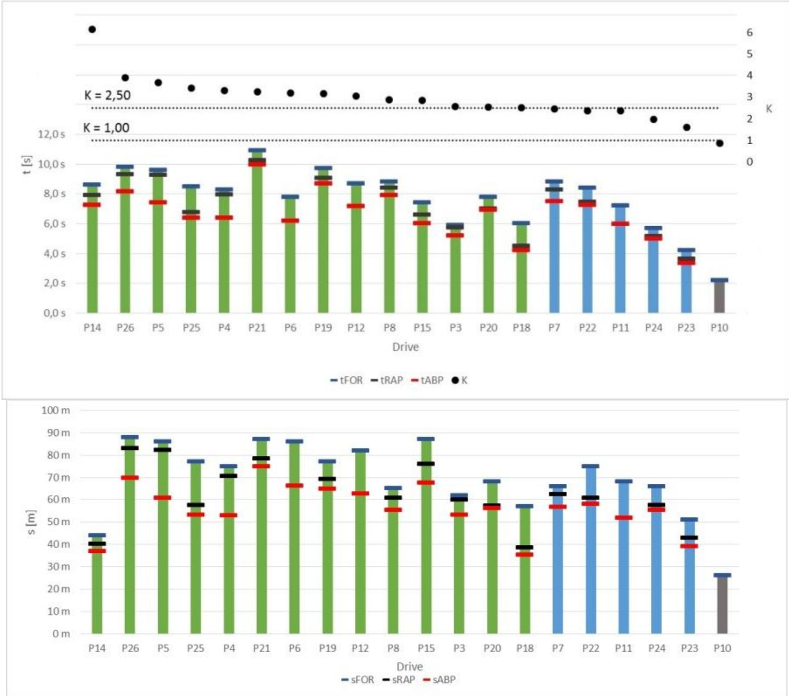


Fig. 4.
CW1 crossing – comparison of driving test results on the CW1 crossing (from above the K coefficient values during individual drives, determined moments of the first optical reactions of the drivers t_{FOR}, moments of accelerating pedal release t_{RAP} and brake pedal activation t_{ABP} and corresponding distances between the vehicle and the crossing s_{FOR}, s_{RAP}, s_{ABP})

Table 2
CW1 crossing – average values of characteristic quantities according to the drive character (distances between vehicles and the crossing at the moment t_{FOR}, t_1, t_{CRW} and corresponding vehicle speeds, drivers' reaction times and proportional times of observation of the figurant by the driver.

Drive character		**Entirely safe**	**With increased danger**	**Dangerous**	**Critical**
Driver		**Decelerates in ordinary way**	**Decelerates intensively**	**Apply the brakes until a stop**	**Does not act in time**
Figurant		**Crosses**	**Crosses**	**Crosses**	**Does not enter the road**
Count of tests		14 tests	5 tests	No measurement	1 test (K = 0,88)
FOR of the drivers	s_{FOR} / v_{FOR}	74 m / 42 km/h	65 m / 50 km/h		26 m / 49 km/h
Figurant's entrance to the road	s_1 / v_1	43 m / 35 km/h	41 m / 43 km/h		Did not enter
Vehicle pass over the crossing	s_{CRW} / v_{CRW}	0 m / 26 km/h	0 m / 28 km/h		0 m / 38 km/h
Reaction times	Δt_{RAP} / Δt_{ABP}	0.71 s / 1.43 s	0.65 s / 1.05 s		-
Proportional time of observation of the figurant by the driver	*Att*	59 %	69 %		87 %

Table 3
CW1 crossing – times needed for control of the situation behind vehicle with the differentiation of the time of the actual scene fixation in the rear view mirror

Control of the situation in the rear view mirror (RM)	**P14**	**P26**	**P5**	**P25**	**P4**	**P21**	**P6**	**P19**	**P12**	**P8**	**P15**	**P3**	**P20**	**P18**	**P7**	**P22**	**P11**	**P24**	**P23**	**P10**
Prior the area of the crossing Δt_{PR} [s]								1.16 0.56	1.12 0.88											
Post the area of the crossing Δt_{PO} [s]														1.06 0.72	0.60 0.24					

5.2. Evaluation of measurements on the CW2 crossing

The results of measurements on the CW2 crossing designed in a modern way and the performed evaluations are graphically compared in Fig. 5. Individual drives are, like those mentioned above, distinguished by colours according to the specified categories for the drive safety. They are sorted by the determined values of K coefficient. From the charts in Fig. 5 it is clear that nine out of twenty drivers managed to respond to figurant at a sufficient distance and also in many cases did not activate the braking pedal (K > 2.5), seven drivers had to brake heavily, although they did not need to stop the vehicle prior to the crossing. Three drivers had to brake to a stop. Only one driver reacted too late (K = 1.08). In this case the figurant realized the possible danger and did not even enter the road. The moments of the first optical reactions of the drivers, the moments of acceleration pedal release, brake pedal activation and corresponding distances between the vehicle and the crossing can be subtracted from the charts in Fig. 5.

The average values of characteristic quantities including length of reaction times and proportional times of observation of the figurant by the drivers are stated in Table 4. From observation of measurement, during which the figurant was crossing the road, it is clear that the average time from the FOR moment to the moment of vehicle pass over the crossing was 7.8 s. During this time the drivers directly observed the figurant for an average time of 5.0 s, which is 64 % of the time they had at their disposal. As in the case mentioned above, they paid him the most attention at a time of his movement on the right edge of the road and in the right traffic lane. The average time of observation of the figurant before the entrance to the road was 3.4 s, which is 81 % of the time 4.1 s that the drivers had at their disposal. In the right traffic lane, the figurant was moving for on average 1.9 s. During this time the drivers were directly watching him for on average 1.4 s, which is 71 % of the time they had at their disposal.

In the monitored stretch only seven drivers of twenty continuously controlled the situation behind the vehicle. Three drivers controlled the situation behind the vehicle during deceleration process, five drivers controlled the situation behind the vehicle immediately after passing over the crossing. The determined times needed for control of the situation behind the vehicle are stated in Table 5. A time of the actual scene fixation in the rear view mirror is stated separately.

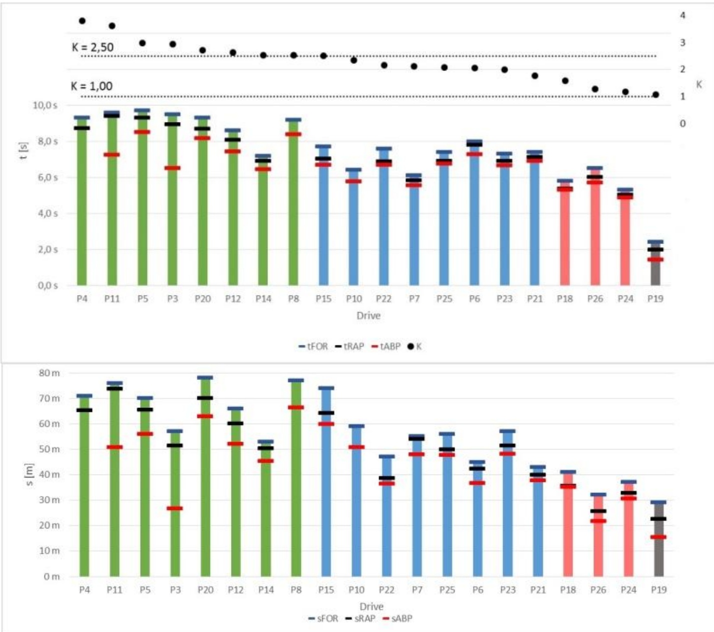


Fig. 5.

CW2 crossing – comparison of driving test results on the CW2 crossing (from above the K coefficient values during individual drives, determined moments of the first optical reactions of the drivers t_{FOR}, moments of accelerating pedal release t_{RAP} and brake pedal activation t_{ABP} and corresponding distances between the vehicle and the crossing s_{FOR}, s_{RAP}, s_{ABP})

Table 4

CW2 crossing – average values of characteristic quantities according to the drive character (distances between vehicles and the crossing at the moment t_{FOR}, t_1, t_{CRW} and corresponding vehicle speeds, drivers' reaction times and proportional times of observation of the figurant by the driver.

Drive character		**Entirely safe**	**With increased danger**	**Dangerous**	**Critical**
Driver		**Decelerates in ordinary way**	**Decelerates intensively**	**Apply the brakes until a stop**	**Does not act in time**
Figurant		**Crosses**	**Crosses**	**Crosses**	**Does not enter the road**
Count of tests		8 tests	8 tests	3 tests	1 test (K=1,08)
FOR of the drivers	s_{FOR} / v_{FOR}	69 m / 42 km/h	55 m / 44 km/h	37 m / 47 km/h	29 m / 46 km/h
Figurant's entrance to the road	s_1 / v_1	24 m / 23 km/h	13 m / 22 km/h	4 m / 11 km/h	Did not enter
Vehicle pass over the crossing	s_{CRW} / v_{CRW}	0 m / 20 km/h	0 m / 14 km/h	0 m / 0 km/h	0 m / 36 km/h
Reaction times	Δt_{RAP} / Δt_{ABP}	0.45 s / 1.49 s	0.43 s / 0.70 s	0.40 s / 0.57 s	0.48 s / 1.04 s
Proportional time of observation of the figurant by the driver	*Att*	70 %	64 %	73 %	100 %

Table 5

CW2 crossing – times needed for control of the situation behind vehicle with the differentiation of the time of the actual scene fixation in the rear view mirror

Control of the situation in the rear view mirror (RM)	P4	P11	P5	P3	P20	P12	P14	P8	P15	P10	P22	P7	P25	P6	P23	P21	P18	P26	P24	P19
Prior the area of the crossing Δt_{PR} [s]															1.00 0.48			0.72 0.44		
Post the area of the crossing Δt_{PO} [s]						1.32 0.88		0.64 0.44								0.56 0.28	1.00 0.52			1.44 1.08

5.3. Evaluation of measurements on the CW3 crossing

The results of measurement on the CW3 crossing and the performed evaluations are graphically compared in Fig. 6. Individual drives are, like those mentioned above, distinguished by colours according to the classification in categories for the drive safety. They are sorted by the determined values of K coefficient. From the charts in Fig. 6 it is clear that while six of the twenty drivers managed to respond to the figurant at a sufficient distance (K > 2.5), nine drivers had to brake intensively, although they did not need to stop the vehicle prior to the crossing. Three drivers had to brake to a stop. Two drivers reacted too late (K = 1.2). In this case the figurant realized the possible danger and did not even enter the road. The moments of the first optical reactions of the drivers, the moments of accelerator pedal release, brake pedal activation and corresponding distances between the vehicle and the crossing can be subtracted from the charts in Fig. 6.

The average values of characteristic quantities including length of the reaction times and proportional times of observation of the figurant by the drivers are stated in Table 6. From observation of measurements, during which the figurant was crossing the road, it is clear that an average time from the FOR moment to the moment of vehicle pass over the crossing was 6.9 s. During this time the drivers directly observed the figurant for an average time of 4.3 s, which is 63 % of the time they had at their disposal. They paid him the most attention at the time of his movement on the right edge of the road and in the right traffic lane. The average time of observation of the figurant before the entrance to the road was 2.6 s, which is 80 % of the time 3.2 s that the drivers had at their disposal. In the right traffic lane, the figurant was moving for on average 2.1 s. During this time the drivers were directly watching him for on average 1.5 s, which is 71 % of the time they had at their disposal.

In the monitored stretch only three out of the twenty drivers continuously controlled the situation behind the vehicle. Only one driver controlled the situation behind the vehicle during the deceleration process, while three drivers controlled the situation behind the vehicle immediately after passing over the crossing. The determined times needed for control of the situation behind the vehicle with the differentiation of a time of the actual scene fixation in the rear view mirror are stated in Table 7.

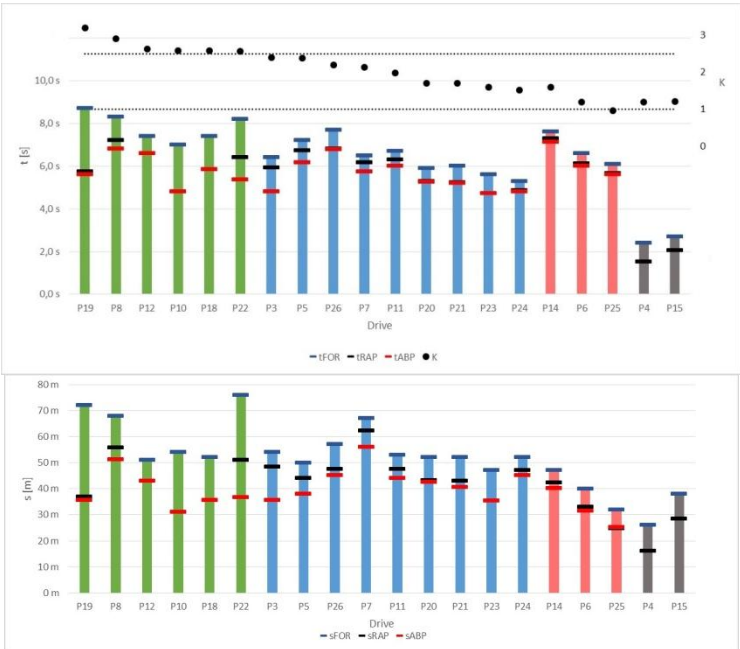


Fig. 6.

CW3 crossing – comparison of driving test results on the CW3 crossing (from above the K coefficient values during individual drives, determined moments of the first optical reactions of the drivers t_{FOR}, moments of accelerating pedal release t_{RAP} and brake pedal activation t_{ABP} and corresponding distances between the vehicle and the crossing s_{FOR}, s_{RAP}, s_{ABP})

Table 6
CW3 crossing – average values of characteristic quantities according to the drive character (distances between vehicles and the crossing at the moment t_{FOR}, t_1, t_{CRW} and corresponding vehicle speeds, drivers' reaction times and proportional times of observation of the figurant by the driver.

Drive character		**Entirely safe**	**With increased danger**	**Dangerous**	**Critical**
Driver		**Decelerates in ordinary way**	**Decelerates intensively**	**Apply the brakes until a stop**	**Does not act in time**
Figurant		**Crosses**	**Crosses**	**Crosses**	**Does not enter the road**
Count of tests		6 tests	9 tests	3 tests	2 tests (K=1,20)
FOR of the drivers	s_{FOR} / v_{FOR}	62 m / 41 km/h	54 m / 47 km/h	40 m / 52 km/h	26 m / 49 km/h
Figurant's entrance to the road	s_1 / v_1	21 m / 31 km/h	21 m / 32 km/h	3 m / 17 km/h	Did not enter
Vehicle pass over the crossing	s_{CRW} / v_{CRW}	0 m / 13 km/h	0 m / 18 km/h	0 m / 0 km/h	0 m / 40 km/h
Reaction times	Δt_{RAP} / Δt_{ABP}	1.95 s / 1.99 s	0.55 s / 0.87 s	0.41 s / 0.52 s	0.76 s / -
Proportional time of observation of the figurant by the driver	*Att*	54%	66%	72 %	88%

Table 7
CW3 crossing – times needed for control of the situation behind vehicle with the differentiation of the time of the actual scene fixation in the rear view mirror

Control of the situation in the rear view mirror (RM)	**P19**	**P8**	**P12**	**P10**	**P18**	**P22**	**P3**	**P5**	**P26**	**P7**	**P11**	**P20**	**P21**	**P23**	**P24**	**P14**	**P6**	**P25**	**P4**	**P15**
Prior the area of the crossing Δt_{PR} [s]				0.50 0.24																
Post the area of the crossing Δt_{PO} [s]	0.80 0.40												0.52 0.20					0.76 0.36		

6. Conclusion

The article demonstrates the possibilities of the investigation of driver's conduct under various road traffic conditions. It points to new possibilities of danger quantification in the areas of pedestrian crossings using K coefficient that enables the quantification of the frequency of dangerous situation occurrence and consideration of the influence of a given traffic solution on road traffic safety. Twenty measurements were compared on three pedestrian crossings designed in various ways. The evaluation results show significant differences in the frequency of the occurrence of dangerous situations. While on the CW1 crossing one critical situation occurred and not even once did the drivers need to brake heavily until a stop, on the CW3 crossing, designed in a modern way, one critical situation occurred as well, but also three situations in which the drivers had to brake until a stop took place. Proper illumination of the area of the figurant's entrance to the road turns out to be an important element in increasing safety level on the CW1 crossing. It is not, however, a complex solution as the area of pedestrians' entrance from the left side in the driving direction of the testing vehicle is illuminated only insufficiently. The well-marked central traffic island, which is a significant visual stimulus for the drivers and draws their attention to a potential danger, turns out to be an important element increasing safety level on the CW2 crossing. The most dangerous situations occurred on the CW3 crossing as two critical situations and three situations requiring braking until a stop took place there. The view limitation in the area of figurant's entrance to the road turns out to be significant by the CW3 crossing.
The $K = 1$ coefficient value, characterizing critical situations, turns out to be characteristic in all cases. All three figurants, under different conditions and independently of each other, evaluated the dangerous situations characterized by the K value close to one as highly dangerous and did not enter the road. At the same time, it turns out that the $K > 2.5$ value properly characterizes expected situations as under these conditions the time from the FOR (of the driver) moment to moment, when the driver starts to adjust the way of driving, extends significantly. The possibility of using records from the driving tests for the identification of risk factors limiting the possibilities of the driver to respond to important stimuli is also the advantage of the eye tracking method.
From the comparison of the reaction time needed for brake pedal activation (see Fig. 7) it is clear that increasing hazardousness of the driving situation arouses the need of its immediate solution and leads to the reaction time reduction. The lower border is, however, naturally limited by human capabilities. It turns out, nevertheless, that in visibility reduced by darkness a reaction time not exceeding one is achievable in a critical situation. On the contrary, the rate of driver's attention (see Fig. 8) grows with increasing hazardousness of the driving situation. The shorter time a driver has to find a solution to the driving situation, the larger part of the time at his disposal he devotes to direct observation of the dangerous object. The most attention was paid to the figurant (by the drivers) before his entrance to the road and during his movement in the right traffic lane and mainly in the time of his movement in the corridor of vehicle pass.

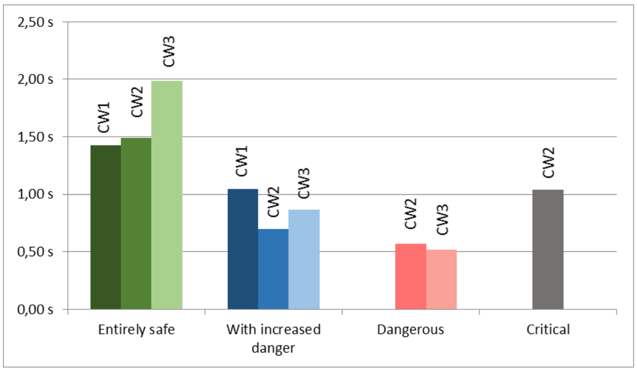


Fig. 7.
All measurements – an average time from the FOR moment to the braking pedal activation moment (or reacting time)

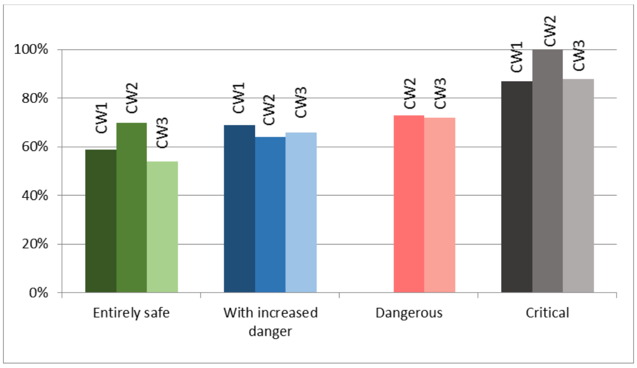


Fig. 8.
All measurements – an average rate of attention that the driver paid to the figurant from the FOR moment to the moment of vehicle pass over the crossing – Att

It turns out that a cause of dangerous situation occurrence can even be an inappropriately chosen moment for control of the situation behind the vehicle using rear view mirrors. During a critical drive on the CW2 crossing (P19 measurement) the driver controlled, by looking into the rear view mirror, the situation behind the vehicle without any evident external stimulus at a distance of ca. 45 m prior to the crossing. This operation lasted for about 1.3 s and the driver noticed the figurant only at a distance of 29 m prior to the crossing. If the figurant entered the road, a very dangerous situation would undoubtedly take place. In the case of other drivers controlling the situation behind the vehicle in the area of the crossing, three drivers have done so after stopping the vehicle and four drivers have done so after significant speed reduction before the crossing. Four drivers observed the figurant in the rear view mirror after they passed over the crossing. An average time needed to look in the rear view mirror, fixation of the scene in the rear view mirror and change of a look back was on average 0.88 s.

Acknowledgements

This contribution was created within solutions of the projects of Specific research called Analysis of driver’s behaviour when passing through accident pedestrian crossings in the city of Brno using the eye tracking method (No. ÚSI-J-16-3713) and Complex analysis of a reaction time of the driver using eye tracking and biosignal scanning (No. FEKT/ÚSI-J-16-3549), solved within Brno University of Technology. Czech Ministry of Education (MŠMT) is a provider of these projects.

References

Belák, M.; Maxera, P.; Semela, M.; Kledus, R.; Bradáč, A. 2016. Analysis the necessary time for driver to assess the situation behind the vehicle. In *Proceedings of International Scientific Conference Expert Forensic Science*, 35-41.
Bella, F.; Silvestri, M. 2015. Effects of safety measures on driver's speed behavior at pedestrian crossings, *Accident Analysis & Prevention*, 83: 111-124.
CSPSD s.p.o. 2015. Dopravní nehody v roce 2015 ve statistických číslech (Traffic accidents in the year 2015 in statistics). Available from Internet: <http://www.cspsd.cz/storage/files/nehody_2015.pdf>.
Google Maps 2016. Available from Internet: <maps.google.com>.

Habibovic, A.; Tivesten, E.; Uchida, N.; Bärgman, J.; Aust, M. L. 2013. Driver behavior in car-to-pedestrian incidents: An application of the Driving Reliability and Error Analysis Method (DREAM), *Accident Analysis & Prevention*, 50: 554-565.

Jurecki, R.S.; Stańczyk, T.L. 2014. Driver reaction time to lateral entering pedestrian in a simulated crash traffic situation, *Transportation Research Part F: Traffic Psychology and Behaviour*, 27(A): 22-36.

Kledus, R.; Semela, M.; Maxera, P.; Kunovský, M. 2013. Analysis Of Drivers Conduct While Driving Over Modern Pedestrian Crossings. In *Proceedings 22nd Annual Congress Firenze 2013*, 107-117.

Mackie, H.W.; Charlton, S.G.; Baas, P.H.; Villasenor, P.C. 2013. Road user behaviour changes following a self-explaining roads intervention, *Accident Analysis & Prevention*, 50: 742-750.

Maxera, P.; Kledus, R.; Semela, M. 2015. Analysis of Drivers' Conduct while Driving over Pedestrian Crossing by Using Eyetracking Method. In *Proceedings of International Scientific Conference Modern Safety Technologies in Transportation - Mosatt 2015*, 140-146.

Ni, Y.; Wang, M.; Sun, J.; Li, K. 2016. Evaluation of pedestrian safety at intersections: A theoretical framework based on pedestrian-vehicle interaction patterns, *Accident Analysis & Prevention*, 96: 118-129.

Pfleger, E. 2009. Blink Analyses and Driver Attention. In *Proceedings of the 1st joint ITAI–EVU Conference*, 25-32.

Pfleger, E. 2012. Hazard recognition and reaction in practice – exact time proof by visualization analysis. In *Proceedings of 21st EVU Congress 2012*, 113-120.

Pfleger, E. 2013. Viewing analysis of experienced vs. not experienced motorcyclists and conclusions about traffic-safety. In *Proceedings of 22nd Annual Congress EVU Firenze*, s. 171-174.

Pfleger, E.; Jechlinger, C. 2010. Disclosure of the Differences in the Navigation and Viewing Behaviour at Day and Night with viewpointsystem® ViewingAnalysis based on Real Examples. In *Proceedings of 19th EVU Congress*, 59-66.

Sullivan, J.; Flannagan, M. 2011. Differences in geometry of pedestrian crashes in daylight and darkness, *Journal of Safety Research*, 42(1): 33-37.

Weyde, M. 2010. Rekonstruktion der Erkennbarkeit von Fussgängern bei Dunkelheitsunfällen unter dynamischen Realbedingungen. In *Proceedings of 19th EVU Congress*, 67-84.

APPLICATION OF WATERBORNE ROAD MARKING PAINT IN CROATIA: TWO YEARS OF ROAD EXPOSURE

Tomasz E. Burghardt[1], Darko Babić[2], Dario Babić[3]
[1] M. Swarovski GmbH, Industriestrasse 10, 3300 Amstetten, Austria
[2,3] University of Zagreb, Faculty of Transport and Traffic Sciences, Vukelićeva 4, 10000 Zagreb, Croatia

Abstract: Waterborne road marking paints with various glass beads were applied two years ago at a test field in Croatia, on a road with Averaged Daily Traffic (ADT) of 8469 vehicles. Retroreflectivity (R_L) was measured periodically using a dynamic test method and the results are provided herein. Performance of the evaluated systems depended mostly on the utilised glass beads, with high-performance glass beads of exceptional roundness and surface quality clearly furnishing the highest R_L after the two seasons; indeed, the systems consisting of waterborne paints and those high-performance glass beads appear to be suitable as three-year marking material. With other evaluated glass beads, all systems were also clearly passing after two years. For the systems durability, the role of road marking paint was secondary, which is expected in the cases where the glass beads are of high quality and appropriately matched. High-performance waterborne paint was somewhat better than the standard fast-dry material. Overall, waterborne paints were found to be an excellent choice, somewhat outperforming simultaneously applied solventborne paints. Their lesser environmental impact is an additional benefit that should be considered.

Keywords: horizontal road markings, waterborne road marking, glass beads, retroreflection, road safety.

1. Introduction

Improvement of road safety is one of the priorities for the European Union (EU). In 2010, an ambitious plan to lower accident rates on EU roads by 50% within the decade has been undertaken. So far, the results seem promising, but the target may still be difficult to reach: In 2014 on EU roads there were reported 1 079 800 vehicular accidents, in which 26 009 people lost their lives and 1 419 800 were injured. That is a meaningful drop since 2010, when in 1 130 484 accidents died 31 490 people (European Road Statistics, 2016).
Horizontal road markings, which guide the drivers, play a meaningful role in accidents reduction. Miller (1992) reported a 20% drop in accidents on roads marked with both edge and centre lines. Subsequent findings not only confirm it, but also pinpoint that their effectiveness is particularly prominent during poor visibility conditions (Migletz et al., 1994), which can be possible because of their retroreflection.

2. Horizontal road markings systems

Horizontal road markings are systems consisting of a pigmented layer and reflective elements. The pigmented materials are usually paints, either water- or solvent-borne. The use of thick-layer durable systems like coldplastics and thermoplastic materials is also frequent, particularly on roads exposed to heavy traffic. There are also several less commonly used marking materials like tapes, epoxy paints, urethane-based systems, or solvent-less acrylic-modified products. Road marking materials were recently reviewed by us (Babić and colleagues, 2015).
The second inalienable part of the road marking systems are glass beads (alternatives to glass beads do exist, but are generally not used because of economic reasons), which furnish retroreflectivity and also protect the paint from abrasive action of traffic. The most commonly used standard glass beads of diameters between 100 and 800 µm are prepared by flame attenuation of ground recycled float glass. Preparation of larger beads, reaching even 2000 µm in diameter, is possible by atomization of virgin glass melt. All prepared glass beads ought to have surface free of defects, be devoid of air bubbles, and be at least 80% round.
Refractive index (RI) is a property related to glass composition: Standard glass beads have RI of 1.5, high-index beads are defined as those with RI above 1.9. Glass beads with high RI are capable of providing significantly larger R_L, exceeding even 2000 mcd/m²/lx, whereas standard glass beads furnish typically about 400 mcd/m²/lx. However, glass beads with high RI are rather costly due to the production process and raw materials and their surface is quite prone to scratching. Therefore, they are seldom used for road marking.
Swarco-proprietary SOLIDPLUS technology permits for preparation of glass beads with low RI, but with retroreflectivity enhanced to reach even 1000 mcd/m²/lx under laboratory conditions. Furthermore, SOLIDPLUS glass beads have high resistance to scratching, as can be seen in Fig. **1**: For the test, the glass beads were embedded in a standard road marking material, subjected to abrasion, and evaluated under a microscope: high-index glass beads failed due to numerous scratches (Fig. **1** centre), standard glass beads passed as only a few scratches were observed (Fig. **1** left), and SOLIDPLUS glass beads were superior with almost no scratches (Fig. **1** right). Such abrasion resistance translates to higher retroreflectivity in the field after exposure to numerous vehicles passing.

[1] Corresponding author: Tomasz.Burghardt@swarco.com

Fig. 1.
Glass beads after abrasive testing: Visible scratching in standard glass beads (left), severe scratching in high-index beads (centre), and almost absence of scratches in SOLIDPLUS product (right)

To provide highest retroreflection, glass beads must be embedded in the pigmented layer at about 50%, as has been shown, based on theoretical calculations, by Grosges (2008). Our proprietary observations confirm the findings. Only with **appropriate application technique** and **correct selection of glass beads** one can achieve the optimum embedment, which is shown in Fig. **2** below. In addition to embedment, appropriate coating of glass beads to furnish chemical adhesion to the road marking materials is critical.

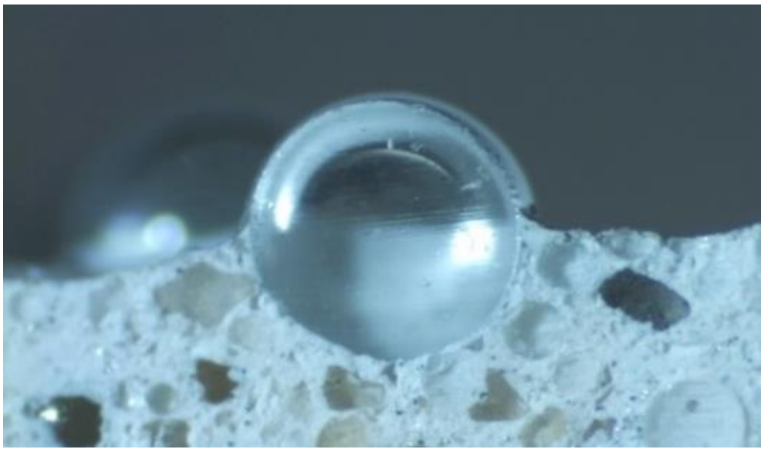


Fig. 2.
Cross-section of a road marking material with a properly embedded glass bead

Despite the fact that the SOLIDPLUS technology is more costly than preparation of standard glass beads, the additional R_L and improved scratch resistance are affordable benefits. SOLIDPLUS beads can be freely blended with standard materials to provide affordable solutions to benefit the applicators seeking fulfilment of the minimum R_L requirement for performance contracts.

3. Road test in Croatia

We have reported the successful application of two waterborne road marking paints and two standard solventborne paints in Croatia (Babić and colleagues, 2015). For the evaluation, various combinations of paints, paint thicknesses, and glass beads were applied as edge lines and single centre line (either solid or intermittent where passing is permitted). Coating of glass beads was matched to the used paints to maximise their adhesion and the beads contained 20% of anti-skid additives to assure appropriate skid resistance and safety under wet conditions. Each of the test areas were 500-m long (in two reported cases 250 m and in one only 100 m). The initial results were meeting the expectations. At present, we can report results after 21 months of normal road usage. The selected road near Zagreb, Croatia, has ADT of 8469 vehicles; hence, the systems were subjected to traffic of 5.3 million vehicles. In addition, there was a snow plough activity during the two winters.
Measurements of R_L were done with a dynamic method, recently described by Babić and co-workers (2014). The readings were done with retroreflectometer ZDR 6020 (Zehntner; of Sissach, Switzerland) mounted on a side of a vehicle, as shown in Fig. **3**. Data collection was done during normal driving, at speeds up to 90 km/h permitted on the test site. This convenient method allows for collecting data every few milliseconds, which is then averaged by the software for 25-m intervals. Additional measurements done with static method are not provided here; however, we can disclose that the results were sufficiently similar. Data collected two weeks after the application was assumed as initial, as is customary in road marking industry.

Areas where the markings were visibly dirty from farming or construction activities, damaged due to road work, or in places that were somehow obscured were marked during data collection; hence, such areas were removed from the results reported herein.

Fig. 3.
Vehicle with side-mounted retroreflectometer

4. Results and discussion

The results achieved with selected road marking systems are provided in Table 1. Averages of results given by the software are reported. In most of the cases, standard deviations were quite low – they are given in Table 1 in parentheses.

The two systems with solventborne paints, toluene-containing (system 1) and aromatic solvents-free (system 2), applied at the edge line on a straight road stretch, furnished good results, meeting the retroreflectivity requirements throughout the test. The systems lost 40-45% of the initial R_L, which is quite a good result. The system without aromatic solvents performed worse than the toluene-based system – not only the initial R_L was lower, but also at the end of exposure lowest R_L amongst all of the systems was measured. Such performance may be expected, because of the use of toluene, which is a good choice for paint, but a very poor choice for environmental reasons (Burghardt et al., 2016). In particular, the ozone-formation capability of toluene is a concern in high-insolation areas, as is being reported separately during this Conference (Burghardt et al., 2016b).

Performance with fast-dry waterborne paint W13 depended on the used glass beads. Systems where SOLIDPLUS glass beads were used performed admirably, either as an edge line (SOLIDPLUS30, containing 30% of SOLIDPLUS glass beads, system 3) or as a short 100 m stretch centre line with passing permitted (SOLIDPLUS100, containing exclusively SOLIDPLUS glass beads, system 4). The loss of R_L was only 12-36%, which is a proof of excellent glass beads adhesion and also resistance of SOLIDPLUS beads to scratching. Paint W13 also performed well at centre line with large glass beads SWARCOLUX50 (glass beads targeting Type II road markings, system 5).

High-performance waterborne paint W15 consistently outperformed the other evaluated systems. The highest retroreflectivity was expectedly obtained with SOLIDPLUS glass beads (system 7 and system 8). It should be noted that system 8, even though it was applied as solid centre line, was located at a road curve, which put more stress on the markings. R_L loss of 36-43% seemed quite high, but still – because of very high initial R_L – these systems could last for another two seasons before the drop below 150 mcd/m²/lx would occur. We assume here the validity and importance of the recently proposed 150 × 150 formula as a standard for horizontal road marking performance (Mosböck, 2016).

The performance of paint W15 with large glass beads SWARCOLUX50 was equally good at edge line with 400-µm and 600-µm wet film applications and at the centre line with 600 µm wet film build (corresponding systems 6, 9, and 10). R_L loss at edge line was lesser than at the centre line (24-36% loss of R_L at edge line, as compared to 52% at the centre), which was according to the expectations.

The use of very large MEGALUX-BEADS® (suitable for Type II markings, systems 11 and 12) also gave surprisingly good results. This is quite important, because with such large glass beads the embedment had to be significantly less than optimal – obviously, chemical interaction between the glass beads coating and the paint permitted for retention of the beads for two seasons and maintaining the required retroreflectivity. R_L loss throughout the exposure period was expectedly high, over 50%. The use of a drying accelerator for the paint did not meaningfully affect the performance. The drying accelerator, intermixed with glass beads, is capable of significant accelerating of drying and development of washout resistance of quick-set waterborne paints (Babić and colleagues, 2015), which is particularly important during marginal application conditions of low temperature and high relative humidity.

Glass beads adhesion to solventborne paints was worse than measured with waterborne paints, which becomes obvious only after considering that for waterborne paints larger glass beads were used (i.e. there was more stress on them). The R_L loss serves as confirmation. The large glass beads are generally not suitable for solventborne paints, because of the paints' poor film formation at thicknesses over 400 µm.

Table 1

Road testing results: Retroreflectivity

System, location	**Paint (applied wet film build) + glass beads type and size range [µm][(a)]**	**—— Retroreflectivity [mcd/m²/lx][(b)] ——**			
		Initial	**10 months**	**21 months**	**Loss**
1, edge line	Solventborne toluene-containing (400 µm) + SWARCOLUX50 200-800	425 (50)	317 (25)	233 (30)	-45%
2, edge line	Solventborne aromatic-free (400 µm) + SWARCOLUX50 200-800	385 (51)	234 (44)	183 (32)	-40%
3, edge line	Waterborne W13 (400 µm) + SOLIDPLUS30 300-1000	516 (81)	527 (60)	329 (57)	-36%
4, centre line, passing[(c)]	Waterborne W13 (400 µm) + SOLIDPLUS100 212-850	623 (84)	679 (57)	476 (156)	-24%
5, centre line, passing	Waterborne W13 (400 µm) + SWARCOLUX50 212-1400	265 (35)	180 (12)	233 (8)	-12%
6, edge line	Waterborne W15 (400 µm) + SWARCOLUX50 212-1400	343 (87)	365 (54)	261 (62)	-24%
7, edge line	Waterborne W15 (400 µm) + SOLIDPLUS30 300-1000	455 (52)	370 (37)	291 (24)	-36%
8, centre line, no passing[(d)]	Waterborne W15 (400 µm) + SOLIDPLUS100 212-850	697 (46)	543 (36)	396 (25)	-43%
9, edge line	Waterborne W15 (600 µm) + SWARCOLUX50 212-1400	338 (53)	290 (52)	231 (40)	-32%
10, centre line, passing	Waterborne W15 (600 µm) + SWARCOLUX50 212-1400	358 (21)	297 (28)	215 (36)	-52%
11, centre line, no passing	Waterborne W15 (600 µm) + MEGALUX-BEADS® 600-2000	422 (22)	276 (42)	204 (47)	-58%
12, centre line, no passing[(d)]	Waterborne W15 accelerated (600 µm) + MEGALUX-BEADS® 600-2000	455 (22)	280 (54)	192 (33)	-52%
(a) In all of the cases, glass beads were applied at 400-450 g/m². (b) Average of the collected measurements, less areas of visible dirt and other unrelated imperfections. Standard deviations are given in parentheses. (c) Stretch only 100 m. (d) Stretch only 250 m.					

In summary, the performance of road marking systems depended more on the glass beads than on the pigmented layer. It is expected in all of the systems where there is an appropriate match between the glass beads, glass beads coating, and the paint. Chemical and physical interactions assure good adhesion of the reflective elements, which protect the paint and thus furnish long-lasting road marking systems. These results overall match those presented at Transportation Research Arena by Burghardt, Pashkevich, and Żakowska (2016a) from a different test field and different arrangement of the markings.

5. Conclusions

Road marking systems consisting of waterborne paints reflectorised with high quality glass beads were shown to be a viable alternative to the currently used solventborne paints. The best performance was measured with SOLIDPLUS glass beads, which due to their exceptional finish and roundness provided systems that after two years had retroreflectivity exceeding 400 mcd/m²/lx. Since the retroreflectivity loss over two seasons was less than 50%, it might be possible that such systems are capable of providing three or even four-season durability. The use of other glass beads provided excellent results as well – in none of the cases retroreflectivity drop below 150 mcd/m²/lx was recorded.

Environmental advantages of the use of waterborne road marking systems are obvious in light of the high system durabilities reported herein.

Note
All of the Tables and Figures are provided by the Authors.

References

Babić, D.; Burghardt, T.E.; Babić, D. 2015. Application and Characteristics of Waterborne Road Markings Paint, *International Journal for Traffic and Transport Engineering*, 52: 150-169.
Babić, D.; Fiolić, M.; Prusa, P. 2014. Evaluation of Road Markings Retroreflection Measuring Methods, *European Scientific Journal*, 3, February Special Edition, ISSN: 1857-7881.
Burghardt, T.E.; Pashkevich, A.; Żakowska, L. 2016. Contribution of solvents from road marking paints to tropospheric ozone formation, *Budownictwo i Architektura*, 15: 7-18.
Burghardt, T.E.; Pashkevich, A.; Żakowska, L. 2016a. Influence of Volatile Organic Compounds Emissions from Road Marking Paints on Ground-level Ozone Formation: Case Study of Kraków, Poland, *Transportation Research Procedia*, 14: 714-723.
Burghardt, T.E.; Pashkevich, A.; Żakowska, L. 2016b. Potential of Tropospheric Ozone Formation from Solventborne Road Marking Paints in Adriatic Sea Basin, *International Conference of Transport and Traffic Engineering; Belgrade, Serbia, 24-25 November 2016* (in press).
European Road Statistics 2016, http://ec.europa.eu/transport/road_safety/specialist/statistics/index_en.htm, accessed 13.07.2016.
Grosges, T. 2008. Retro-reflection of glass beads for traffic road stripe paints, *Optical Materials*, 3010: 1549-1554.
Migletz, J.; Fish, J.; Miles, J. 1994. Roadway Delineation Practices Handbook, U. S. Department of Transportation, Federal Highway Administration, Washington, DC, U. S. A.; Technical Report FHWA-SA- 93-001.
Miller, T.R. 1992. Benefit–cost analysis of lane marking, *Transportation Research Record*, 1334: 38–45.
Mosböck, H.; Burghardt, T.E. 2016. The Importance of Road Markings for Road Safety and Modern Traffic Management, *European Road Infrastructure Congress; Leeds, the United Kingdom, 18-20 October 2016* (in press).

THE COMPARISON OF THE ACCIDENT RATES IN HEAVY TRANSPORT SECTORS OF EUROPE AND USA

Jonas Matijošius[1], Kristina Čižiūnienė[2], Artūras Petraška[3], Edgar Sokolovskij[4]
[1,2,3,4] *Vilnius Gediminas Technical University, Vilnius, Lithuania*

Abstract: Heavy transport vehicles are the main units in the supply chain system. In one hand, it is very important to vouch the efficient system work, to prevent the accidents, on another hand to minimize the system costs. This is very important in the two biggest world economics – Europe and USA. The comparison of the accident rates - the distribution of traffic events that cause deaths according to types of event sites, traffic event situations (collisions against motorcyclists and bicyclists, cars) were presented at this article.

Keywords: accident rates, Europe, USA, transport sectors.

1. Introduction

In Europe, a collision of a car with a truck often results serious injuries or even deaths of the drivers. Most frequently, the driver of the car is a causer of the traffic event. As it is emphasized in a majority of papers, a probability of coming into collision with a truck is much lower than with another vehicle (Dell’Acqua et al., 2016). A probability of causing a traffic accident by a truck is 3 times less, as compared to a car. A low number of such accidents may be explained by the circumstance that heavy trucks are usually used on highways or other roads where the relative accident rate is considerably lower; however, such accidents, as a rule, cause serious injuries or deaths.
As it is pointed out in the report of „Volvo Trucks“ on traffic safety and traffic events on European roads, nine of ten traffic events where load-carrying vehicles are involved are caused by human factors. According to Kleinauskas (2013), 90% of total number of traffic events where trucks are involved occur because of human factors (unduly estimation of the road trajectory, fatigue, inattention and so on). In majority of traffic events where drivers of load-carrying vehicles suffer, no vehicles of other types are involved. The most frequent cause of a traffic event is off-going of a truck.
The aim of article – to compare the accident rates in heavy transport sectors of Europe and United State of America.
The tasks of the article:

- To make overview of traffic event causes in USA and Europe;
- To identify causes of heavy transport traffic events.

2. The analysis on traffic event causers in USA and Europe

One of the topical problems of heavy transport sector is an ignorance of safety belts by the drivers: over a half of the total number of drivers involved in truck driving on European roads do not use the safety belts. On collisions of trucks with cars, 36% of car drivers violated at least two provisions of the traffic rules, whereas only 11% of truck drivers committed several offences simultaneously. The report of „VOLVO Trucks“ for the year 2013 that drink-driving was not one of the main causes of traffic events (where drivers of trucks were involved) (Kleinauskas, 2013). Only 0.5 % of truck drivers having caused a serious traffic event were intoxicated by alcohol or other psychotropic substances. However, 15–20% of car drivers having caused a serious traffic event were intoxicated by alcohol or other psychotropic substances. So, it is notable that this difference is considerable. The groundless public opinion on truck driver as alcohol users may be ignored (Detailed Star Rating, 2014; Zefreh and Török, 2016).
The diagrams of the most frequent causers of traffic events have been preliminary formed. Let’s compare the situation in Europe and USA. In all traffic events where at least one load-carrying vehicle was involved, the causers were distributed as follows:

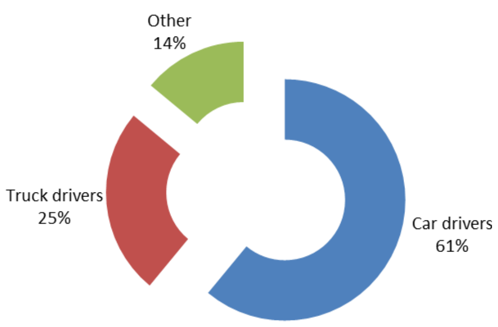


Fig. 1.
The analysis on traffic event causers in USA

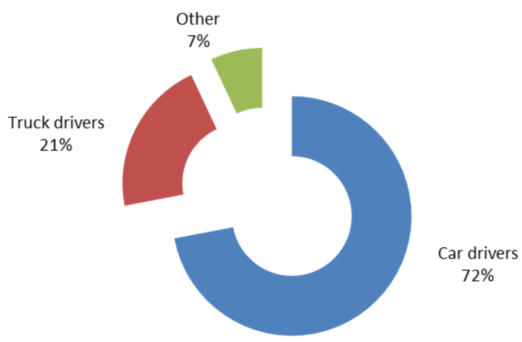


Fig. 2.
The analysis on traffic event causers in Europe

[1] Corresponding author: jonas.matijosius@vgtu.lt

Both in Europe and USA, the statistics show that car drivers cause from 61% to 72% of the total number of traffic events. The statistical data are very much alike. Drivers of trucks cause only 23% of the total number of traffic events. Other causes of traffic accidents include technical problems of the vehicles, weather conditions or the road surface defects.

3. The causes of traffic events

The statistics shows that a majority of traffic events world widely occur in towns; however, the events that cause deaths are distributed as follows:

Fig. 3.
The distribution of traffic events that cause deaths according to types of event sites

Both in Lithuania and other European Union Member States, most traffic deaths occur out of towns. Because velocities of vehicles are higher out of towns, the consequences of traffic events there are more serious. 64% of traffic deaths occur on roads out of towns and 36% – in towns. On comparing all traffic deaths, the following distribution is revealed.

Table 1
The distribution of traffic deaths

Traffic participants	USA	Europe
Car drivers and passengers	76%	54%
Bicyclists, motorcyclists and pedestrians	9%	40%
Truck drivers	15%	6%

Source: Detailed Star (2016)

In America, 76% traffic fatalities caused by a collision with a truck are deaths of car drivers and passengers. However, in Europe this indicator is lower – 54%. Within the territory of USA, deaths of bicyclists and motorcyclists are caused only by 9% of the total number traffic events. In Europe, this indicator is 40%. Why? We think the cause includes a number of aspects. First, highways are broader in USA; second, choppers are very popular there for a long time, so people got used to meet them. The last aspect is related to truck drivers: within the territory of USA they die in 15% of the total number of traffic accidents caused by a collision with the truck, whereas in Europe – in 6% of total number of traffic accidents. The said indicators may appear to be unexact, because sometimes only one driver survived after an accident and his history could be incorrect (Ministry of Transport and Communication, 2014).
According to data from Michigan University, after analysis of 8’309 traffics events where trucks were involved, it was found that car drivers caused 89% of front collisions and 88% of lateral collisions against an oncoming heavy vehicle; in addition, they caused 80% rear-end collisions and 72% lateral collisions on movement of both vehicles in the same direction (Godoy et al., 2015).
American National Highway Traffic Safety Administration has analyzed 10’092 traffic accidents and provided similar figures. According to its data, 91% of front or lateral collisions against oncoming vehicles were caused by car drivers. In addition, they were responsible for 71% of front collision and 77% of lateral collisions on movement in the same direction (Godoy et al., 2015).
In addition, in course of the research, the most frequent causes of traffic events were established:

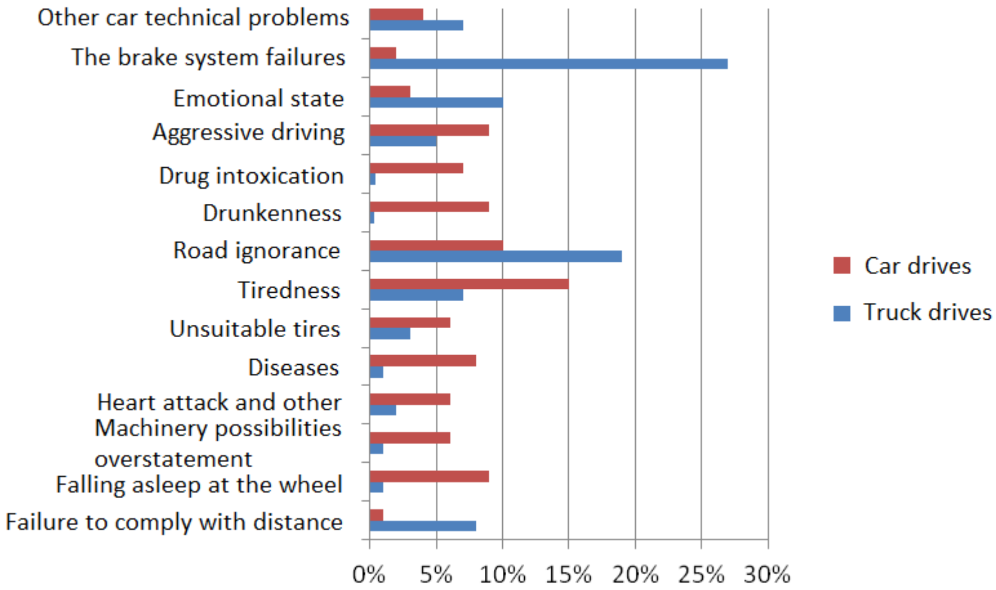


Fig. 4.
The causes of traffic events

The most frequent cause of a traffic event for a load-carrying vehicle is a fault of its braking system (27%). In our opinion, this indicator is too high. In course of the analysis of studies by other authors, no data supporting the statement that a majority of traffic events are caused by a fault of the brakes were obtained. Car drivers most commonly cause traffic events through their fatigue (15%). The concept of fatigue is hardly determinable, because each person may subjectively assess, whether he (she) is tired or not. Usually a driver perceives a lack of sleep or rest. The other aspect is poor awareness of the road (19%). This indicator is high both for cars and the heavy transport sector. Each driver ever experienced the stress caused by poor awareness of the road: at such a moment, the behavior of the driver becomes irresponsible and he may cause an accident situation with serious consequences. Other factors that may cause traffic events include sleep-driving, safe distance ignorance, unfit tires and so on (Novikovienė, 2009; Li and Fratrović, 2016).
A majority of studies confirm that usually traffic injuries or traffic deaths occurred in the following situations:

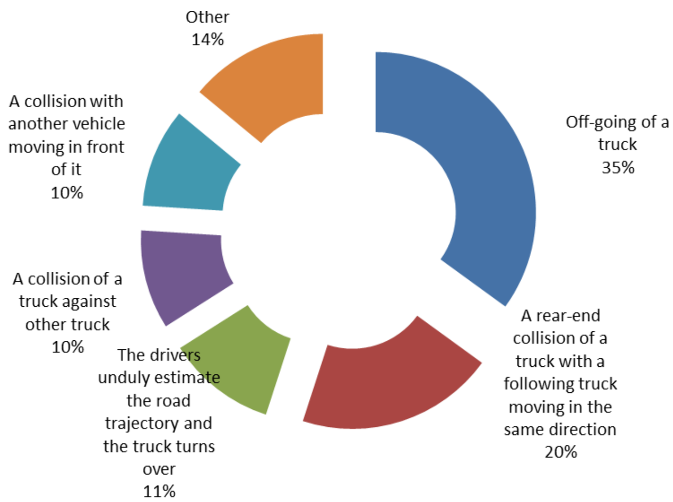


Fig. 5.
Traffic events

It was found that a majority of traffic event was caused by off-going of a truck (35%). The causes of this factor are abundant, including the slippery road surface or fatigue of the driver. They also may include road dimples that violate the uniform movement of the truck or other causes. Other very frequent situation is a rear-end collision of a truck with a following truck moving in the same direction (even 20% of cases). Many traffic events are caused when the drivers unduly estimate the road trajectory and the truck turns over (11%). 10% of traffic situations are formed separately by a collision of a truck against other truck or another vehicle moving in front of it. After all the above-mentioned situations, a survival of the driver is almost impossible (Kleinauskas, 2013).
The numbers of heavy injuries or deaths of drivers and passengers of cars after a collision against a truck in the totality of such traffic events:

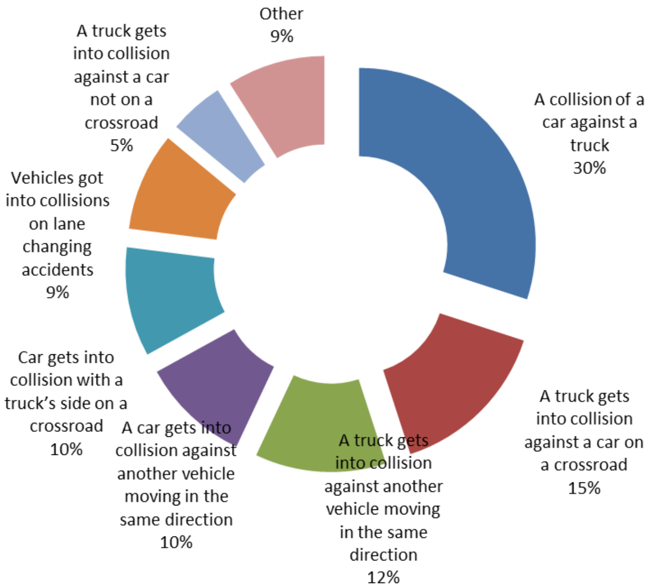


Fig. 6.
Traffic event situations (a collision against a car)

It was found that a probability of survival or avoidance of serious injuries on a collision of a car against a truck (the rate of such situations is up to 30%) is low. A higher probability of avoidance of a serious injury or death is typical for a situation, when a truck gets into collision against a car on a crossroad. Maybe, it is caused by considerably lower velocities at crossroads (Buzási and Csete, 2016). Very frequently, a truck gets into collision against another vehicle moving in the same direction or a car gets into collision with a truck's side on a crossroad. Drivers and passengers also suffered injuries when vehicles got into collisions on lane changing accidents (9%) (Kleinauskas, 2013).
The remained part of the injured and killed includes motorcyclists, bicyclists and pedestrians. When they are involved in traffic events, they suffer serious injuries, if:

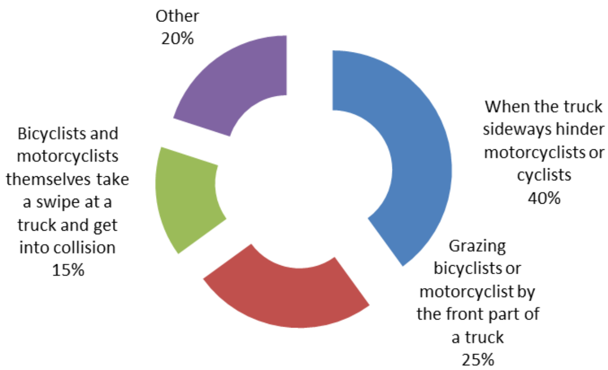


Fig. 7.
Traffic event situations (collisions against motorcyclists and bicyclists)

Usually, in case of a sideswipe by a truck, avoidance on injury of the motorcyclist or the bicyclist is almost impossible. Such traffic events form 40% of all traffic events. Many traffic events are caused by grazing bicyclists or pedestrians by the front part of a truck. It seems to be strange but bicyclists and motorcyclists themselves take a swipe at a truck and get into collision against it in 15% of situations. We have not found such high percentage in studies by other authors however, such situations when a motorcycle moving with a high velocity takes through a carelessness of its driver a swipe at a truck vehicle sometimes occur (Gaddam et al., 2016; Gaal et al., 2015).
In summary, it may be stated that a probability of causing a traffic event by a truck is considerably lower, as compared to other types of vehicles (for example, it is 3 times lower, as compared to a car). The groundless public opinion on heavy drinking of truck drivers should be denied. In course of various studies in was found that only in 0.5% of traffic events where at least one truck was involved the drivers were intoxicated by alcohol, whereas this indicator for car drivers amounts to 17.5%. Talking of the distribution of traffic events, it should be stated that the number of traffic deaths out of towns is higher, as compared to towns. This difference is caused by considerably higher velocities of vehicles out of towns. Most frequent causes of traffic events are various – they vary from a fault of the vehicle to poor awareness of the road. Frequently, traffic events are caused by sleep-driving or ignorance of a safe distance. However, a majority of traffic event are caused by off-going of a truck (35%). Very frequently, traffic events are caused by taking a swipe of a truck at another truck that moves in front of it and so on (Kleinauskas, 2013).

4. Conclussions

1. An analysis of the conception of accident rate in scientific literature shows that its key element is a vehicle. However, it should not be forgotten that a bicyclist or even a pedestrian may be involved in a traffic event. So, it is spoken about persons whose actions may be directly or indirectly important for a traffic event.
2. According to causes of their appearance, traffic events are classified to those occurred through a fault of humans, impact of natural forces or by a matter of chance. Errors of drivers while driving the vehicles are the principal cause of a majority of traffic events. Other causes of traffic accidents include technical problems of the vehicles, weather conditions or the road surface defects.
3. One of the main problems of heavy transport sector in Europe is an ignorance of safety bells by the drivers.
4. The main causes of heavy transport traffic events are: malfunction of brake system; unawareness the road; emotional conditions; failure to comply with the distance; fatigue.
5. The completed analysis of scientific literature showed the existing situation of accident rates in the heavy transport sector and disclosed its problems both in Europe and USA. It was concluded that most frequently traffic events occur through a fault of drivers. Talking of the situation of accident rates in the heavy transport sector, it should be stated that the situation is being improved, but this process is slow, in spite of increasingly growing number of traffic safety measures.

Literature

Buzási, A.; Csete, M. 2016. Modified Scorecard Method for Evaluating Climate Aspects of Urban Transport Systems, *Periodica Polytechnica Social and Management Sciences*, 24(1): 65-73.

Dell'Acqua, G.; De Luca, M.; Prato, C.G.; Prentkovskis, O.; Junevičius, R. 2016. The impact of vehicle movement on exploitation parameters of roads and runways: a short review of the special issue, *Transport*, 31(2): 127-132.

Detailed Star Rating methodology [interaktyvus]. Available from Internet: <http://www.irap.net/en/about-irap-3/methodology>.

Gaal, G.; Horváth, E.; Török, Á.; Csete, M. 2015. Analysis of Public Transport Performance in Budapest, Hungary, *Periodica Polytechnica Social and Management Sciences*, 23(1): 68-72.

Gaddam, H.K.; Chinthireddy, A.; Rao, K.R. 2016. Comparison of Numerical Schemes for LWR Model under Heterogeneous Traffic Conditions, *Periodica Polytechnica Transportation Engineering*, 44(3): 132-140.

Godoy, J.; Pérez, J.; Onieva, E.; Villagrá, J.; Milanés, V.; Haber, R. 2015. A driverless vehicle demonstration on motorways and in urban environments, *Transport*, 30(3): 253-263.

Kleinauskas, V. 2012. Vilkikų avarijos: kokiais atvejais dažniausiai nepavyksta išvengti mirties ar sužalojimų [Vehicle accident: in which cases often fail to prevent death or injury], [In lithuanian]. Available from Internet: <http://www.delfi.lt/auto/patarimai/vilkiku-avarijos-kokiais-atvejais-dazniausiai-nepavyksta-isvengti-mirties-ar-suzalojimu.d?id=59280529>.

Kleinauskas, V. 2013. Vilkikas keliuose ir žudikas ir saugumo garantas [Truck on the road and a killer and a guarantee of security], [In lithuanian]. Available from Internet: <http://m.kauno.diena.lt/naujienos/nelaimes/vilkikas-keliuose-ir-zudikas-ir-saugumo-garantas-203265>.

Li, L.; Fratrović, T. 2016. Analysis of factors influencing the vehicle damage level in fatal truck-related accidents and differences in rural and urban areas, *PROMET - Traffic&Transportation*, 28(4): 331-340.

Ministry of Transport and Communications. Towards Accessible Transport. Available from Internet: <http://www.transportresearch.info/web/programmes/programme_details.cfm?ID=4972>.

Novikovienė, L. 2009. Eismo įvykių kriminalistinė charakteristika ir jos reikšmė eismo įvykių prevencijai [Traffic accidents Forensic characteristics and its significance accident prevention], [In lithuanian], *Verslo ir teisės aktualijos [Current Issues of Business and Law]*, 4: 185-207.

Zefreh, M.M.; Török, Á. 2016. *I*mproving Traffic Flow Characteristics by Suppressing Shared Taxis Maneuvers, *Periodica Polytechnica Transportation Engineering*, 44(2): 69-74.

AUTHOR INDEX

Bukova, Bibiana	*Universty of Zilina, Faculty of Operation and Economics of Transport and Communication, Department of Railway Transport, Zilina, Slovakia*	937
Bulejko, Pavel	*Brno University of Technology, Faculty of Mechanical Engineering, Czech Republic*	616
Burciu, Stefan	*Transport, Traffic and Logistics Department, Transport Faculty, University Politehnica of Bucharest, Bucharest, Romania*	476, 928
Burghardt, Tomasz	*M. Swarovski GmbH, Amstetten, Austria*	499, 1092
Cafiso, Salvatore	*Department of Civil Engineering and Architecture, Catania, Italy*	211, 438, 655
Capace, Brunella	*University of Catania, Department of Civil Engineering & Architecture, Catania, Italy*	438
Capaldo, Francesco Saverio	*Department of Civil, Architectural and Environmental Engineering (DICEA), University of Naples Federico II, Italy*	122, 694, 703, 712
Caramatescu, Adrian	*"Dunarea de Jos" University of Galati, Naval Architecture Faculty, Galati, Romania*	265
Castro-Malpica, María	*Depto. de Ingeniería Civil: Transporte y Territorio, E.T.S.I. de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Madrid, Spain*	75, 88
Catalfamo, Domenica	*Provincia of Reggio Calabria, Reggio Calabria, Italy*	800
Cela, Liljana	*South East Europe Transport Observatory (SEETO), Serbia*	886
Cempírek, Václav	*Jan Perner´s Transportation faculty, University of Pardubice, Pardubice, Czech Republic*	375, 855
Cerna, Lenka	*University of Žilina, The Faculty of Operation and Economics of Transport and Communications, Žilina, Slovakia*	454
Chilà, Giovanna	*Provincia of Reggio Calabria, Reggio Calabria, Italy*	800
Chodur, Janusz	*Institute of Road and Railway Engineering, Cracow University of Technology, Poland*	675
Coraggio, Giovanni	*Mobility and Transport Section, Province of Salerno, Italy*	712
Cormos, Ciprian Angel	*Telematics and Electronics for Transport Dept., Transport Faculty, Politehnica University of Bucharest, Bucharest, Romania*	880
Costea, Ilona Madalina	*Telematics and Electronics for Transport Dept., Transport Faculty, Politehnica University of Bucharest, Bucharest, Romania*	880
Costescu, Dorinela	*University Politehnica of Bucharest, Faculty of Transport, Transports, Bucharest, Romania*	476
Cristea, Catalin	*Dunarea de Jos" University of Galati, Naval Architecture Faculty, Galati, Romania*	265
Crnogorac, Dušan	*University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia*	165
Crudu, Liviu	*Faculty of Naval Architecture, University "Dunarea de Jos" of Galati, Romania, NASDIS srl, Galati, Romania*	250
Csiszár, Csaba	*Budapest University of Technology and Economics (BME), Faculty of Transportation Engineering and Vehicle Engineering (KJK), Department of Transport Technology and Economics (KUKG) Budapest, Hungary*	533
Çodur, Muhammed Yasin	*Erzurum Technical University, Engineering and Architecture Faculty, Department of Civil Engineering, Erzurum, Turkey*	642, 683
Čamaj, Juraj	*University of Žilina, The Faculty of Operation and Economics of Transport and Communications, Department of Railway Transport, Žilina, Slovakia*	409, 429, 955
Čejka, Jiří	*Institute of Technology and Business in České Budějovice, Department of Informatics and Natural Sciences, Czech Republic*	851
Čelar, Nikola	*University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia*	670
Čičević, Svetlana	*University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia*	165
Čiziūnienė, Kristina	*Vilnius Gediminas Technical University, Vilnius, Lithuania*	1097
Čokorilo, Olja	*University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia*	36, 49, 205
Čolaković, Alem	*University of Sarajevo, Faculty of Traffic and Communications, Sarajevo, Bosnia & Herzegovina*	205
Čorić, Mirko	*University of Split, Faculty of Maritime Studies, Split, Croatia*	200
D'Agostino, Carmelo	*University of Catania, Department of Civil Engineering & Architecture, Catania, Italy*	438
Daniš, Jozef	*University of Žilina, Faculty of Operation and Economics of Transport and Communications, Department of Railway Transport, Žilina, Slovakia*	429, 955
De Luca, Mario	*Department of Civil, Architectural and Environmental Engineering (DICEA), University of Naples Federico II, Italy*	122, 616, 694, 703
de Santos-Berbel, César	*Depto. de Ingeniería Civil: Transporte y Territorio, E.T.S.I. de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Madrid, Spain*	75, 88
Delfino, Emanuele	*University of Catania, Department of Civil Engineering & Architecture, Catania, Italy*	438
Di Graziano, Alessandro	*University of Catania, Department of Civil Engineering & Architecture, Catania, Italy*	438
Dobrodolac, Momčilo	*University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia*	980
Dolinayová, Anna	*University of Žilina, Faculty of Operation and Economics of Transport and Communications, Department of Railway Transport, Slovakia*	429, 955

Záhorská, Hana	*Brno University of Technology, Faculty of Civil Engineering, Czech Republic*	737
Żakowska, Lidia	*Kraków University of Technology, Civil Engineering Department, Transport Section, Kraków, Poland*	499
Žilionienė, Daiva	*Department of Roads, Vilnius Gediminas Technical University, Lithuania*	694
Živanović, Predrag	*University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia*	793
Žlak, Boštjan	*Faculty of Maritime studies and transport, Portorož, Slovenia*	282
Žáčik, Nikolas	*University of Žilina in Žilina, Faculty of Operation and Economics of Transport and Communications, Žilina, Slovakia*	31

ictte

9 788691 615338 >