RANKING OF LOGISTICS SYSTEM SCENARIOS USING COMBINED FUZZY AHP-VIKOR MODEL

Snežana Tadić[1], Slobodan Zečević[2], Mladen Krstić[3]

[1, 2, 3] *University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11000, Belgrade, Serbia*

Abstract: Ranking of the logistics system scenarios of the Central Business District (CBD) of the city is performed in this article using the multi-criteria decision-making (MCDM) model which combined the methods of fuzzy "Analytical Hierarchy Process" (FAHP) and "Višekriterijumska Optimizacija i kompromisno Rešenje" (VIKOR). FAHP is applied for obtaining the weights of the criteria defined on the basis of conflicting goals of different stakeholders, and VIKOR method is applied for obtaining the final ranking of the logistics system scenarios.

Keywords: city logistics, central business district, logistics system scenario, FAHP-VIKOR.

1. Introduction

Logistics system scenario for the city or certain urban area is defined in accordance with the requirements of stakeholders, i.e. participants of city logistics (shippers, receivers, carriers, logistics service providers, residents, city government). Considering that participants have different, often conflicting goals and interests, it is necessary to find a compromise solution. This problem can be solved by defining a large number of criteria and applying MCDM methods.

In this article, the problem of ranking logistics system scenarios for the Central Business Danube District (CBDD) of Belgrade is solved using the MCDM model which combines AHP in fuzzy environment (FAHP) and VIKOR in conventional form. This area is foreseen for the development of various business and commercial facilities, and new plan also requires new logistics solutions, defined in this article in the form of three scenarios. Ranking of scenarios is carried out in relation to the criteria defined in accordance with the requirements of different structures and functions of the city. The weights of criteria are obtained by using FAHP method which is simple to use, easily adaptable to the problems of different dimensions and can take into account both quantitative and qualitative criteria. However it can be problematic in terms of presenting the dependencies between the criteria and alternatives, therefore the VIKOR method is used in this article for obtaining the final order of the alternatives (scenarios). The methods results in the compromise solutions, established by mutual concessions, based on which the ranking of alternatives is performing.

---

[1] Corresponding author: s.tadic@sf.bg.ac.rs

2. Defining the Problem

Evolution of urban areas caused the change of the form and physical components of procurement, storage and distribution of goods. In the initial stages of development, ports, harbors and squares represented the commodity gates for urban areas. With the spatial expansion of cities, the development of transport infrastructure and rising prices of urban land, the stopping points of macro-distribution flows are moving towards the peripheral zones. The growth of road transportation, the expansion of network of warehouses, logistics centers, as well as increased demands in terms of quality and variety of logistics services have resulted in a significant increase in the number of commercial vehicles and worrying loss of vitality of come cities. Existing regulations and policies of urban freight transport and logistics, in most cases cannot fully respond to the significant changes that have taken place in the use of the land, as well as in the sectors of production, distribution and consumption. The space devoted to logistics activities (freight terminals, city ports, warehouses) disappears from the cities. Expensive urban land changes its purpose, i.e. new commercial and housing facilities that generate significant flows of goods and require a modern concept of logistics are developing.

Belgrade is, like many other cities on the riverside, mainly developed and radial-concentric spread in regard to the traditional center and the river port. In the initial stages of development, many trade and distribution as well as industrial firms favorably inhabited the port and its surroundings and developed their own warehousing and distribution activities. Therefore the area of CBDD, in spite of being a very valuable land, is occupied by the storage and handling systems with the outdated technologies, runs a large number of vehicles and in many cases performs the logistics function for users who are not in the immediate area of the city of Belgrade. In addition to the outdated concept of structuring, inadequate utilization of space and outdated technology, this area also lacks logistics scenario that would be consistent with the city development concepts.

The observed urban area, CBDD, becomes an attractive location for more profitable business and commercial contents, which requires the restructuring of existing urban units. The basic idea is to free the observed space of unnecessary logistical structures, to maintain and modernize the system of logistics for the CBD and coordinate it with the concept of a combined centralized-decentralized logistics system of the city (Master plan of Belgrade, 2021). Analysis of logistics scenario of the CBDD and selection of the best solution for a broad set of interests is a central issue and task discussed through the case study in this article.

3. CBDD Logistics Systems Scenarios

The key elements for defining future logistics concept for CBDD are: causes for settlement of the observed area; the possibility of displacement, dislocation; the necessity of certain systems existence at the location; the place and role of CBDD's logistics system in the logistics of the city; and compatibility of logistics facilities with new development plans. In addition to that, changes of the port system ownership and their business visions had a significant impact on the setting of the three scenarios of the CBDD logistics system (Zečević, 2006):

- *Sc.1: The scenario of minimal infrastructural changes.*
- *Sc.2: The scenario of significant changes.*
- *Sc.3: The scenario of complete changes.*

Scenario Sc.1 involves the retention and modernization of existing structures and subsystems at the observed area (Fig. 1). The port, which would remain in CBDD, would retain certain functions, primarily intermodal transport function. In this case, it is expected further development and modernization of intermodal terminals. The existing storage and distribution systems could increase their efficiency with the use of new technologies and it is possible to expect the development of new, modern logistics systems, which would be acceptable solutions for observed area in terms of architecture and civil engineering. In functional sense, new logistics systems would be the answer to the growing need for VAL services (Value Added Logistics), deliveries to specific assumption zones (pickup points), professional warehousing services, reverse logistics services, etc.
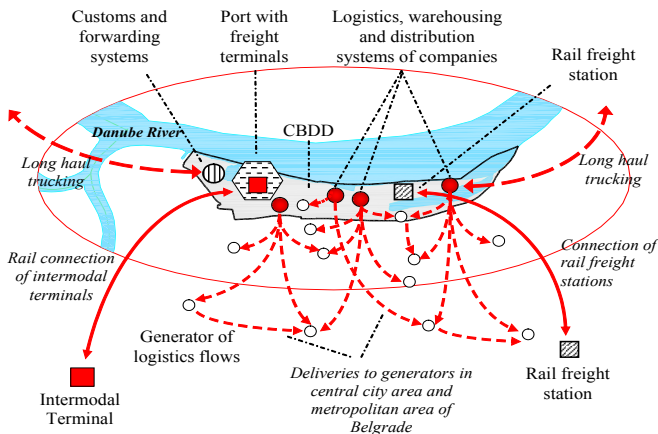

Fig. 1.
Logistics System of CBDD According to Scenario Sc.1
Source: Tadić and Zečević (2009)

Scenario Sc.2 is based on the reduction of distribution and storage systems, as well as shipping, customs and other related activities that are not necessary for the supply of CBD. This scenario implies the modernization of intermodal terminal as trimodal node and the development of a CLT for consolidated deliveries to generators in the gravity area (Fig. 2). These two sub-systems have the ability for railway connection with intermodal terminals in other locations, freight villages (FV) on the edge of the city, using the system of shuttle trains. This would lead to significant reduction of railway facilities, but it would enhance the role of railway in effective connection of this area. CLT would supply the CBD with a variant of small commercial eco-vehicles.
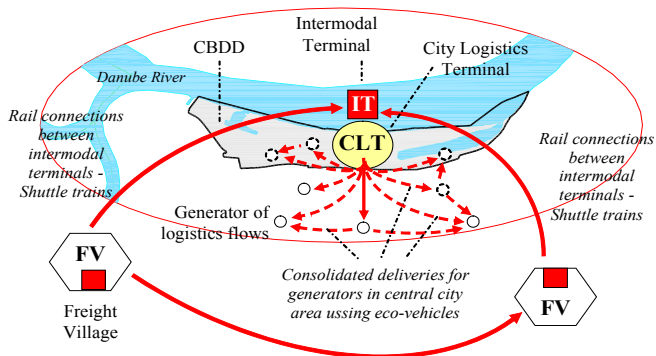
Fig. 2.
Logistics System of CBDD According to Scenario Sc.2
Source: Tadić and Zečević (2009)

Scenario S3 imply dislocation of all existing port complex facilities and railway freight station, while the entire observed area of CBDD remains business and shopping center with associated restaurants, cultural and sports facilities. This scenario would be in accordance with the "logistics sprawl" (Dablanc and Rakotonarivo, 2010) which becomes a worldwide phenomenon, and imply that logistics is increasingly taken away from the heart of the city. However, commercial contents that would settle the area of CBDD, together with the existing commercial contents in central city area can't operate without logistics. Attractiveness and functionality of the system requires accompanying logistics system with a minimum and efficient configuration which, in the physical and traffic terms, can be done by introducing CLT. The goods would be delivered to the terminal from the logistics center in another location in the city, using the cargo tram and goods distribution to the generators in the CBD would be performed with electric vehicles (Fig. 3).
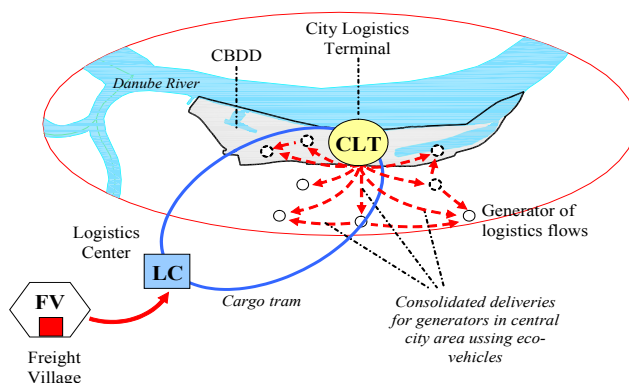

Fig. 3.
Logistics System of CBDD According to Scenario Sc.3
Source: Tadić and Zečević (2009)

4. Criteria for Assessing Logistics System Scenarios

Criteria used for the evaluation of the CBDD logistics system are described below (Tadić et al., 2014b):

C1. ***The degree of congestion caused by heavy freight vehicles on the access points and roads in CBDD.*** With dislocation of systems which, in technological and spatial sense, are not related to the port and intermodal transport and with the consolidated distribution of goods in scenarios Sc.2 and Sc.3, the number of freight vehicles would be significantly reduced, and thus the degree of traffic congestion.

C2. ***The degree of space occupancy by the logistics systems that are not needed in the CBDD.*** According to scenario Sc.1, a certain number of CBDD logistics system users make deliveries to recipients outside of Belgrade from this site. By dislocating these activities and concentrating only on supplying the CBD, occupied areas can be significantly reduced in scenario Sc.2, and especially in scenario Sc.3.

C3. ***Investment for the development of systems****.* Investments for systems development according to scenarios Sc.2 and Sc.3 are significant and depend on the micro-location, size and structure of the planned facilities.

C4. ***Costs of goods delivery.*** According to previous researches, delivery costs are reducing by using CLT and concept of flows consolidation for multiple users.

C5. ***Time losses in inbound-outbound transport.*** These losses could be substantial in scenario Sc.1.

C6. ***The quality of logistics service.*** By using modern storage systems and systems for tracking and vehicle navigation during delivery, logistics service quality parameters could be significantly improved. Accordingly scenarios Sc.2 and Sc.3 are better solutions for all users who may, in the future, be supplied from CBDD.

C7. ***Ecological and energy aspects.*** By eliminating long haul, and applying the concept of consolidation and environmentally acceptable systems and technologies of transport, the total number of road freight vehicles, and thus the negative environmental impacts and energy consumption could be significantly reduced compared to current state.

C8. ***Security aspect.*** Reduction of the amount of traffic and congestion on city roads reduces the number of conflicting situations. According to this parameter it is evident an advantage of scenarios Sc.2 and Sc.3.

C9. ***Logistics chains complexity.*** Every stopping of the goods flow and its transformation in logistics centers increases the logistics chains complexity. Application of scenario Sc.3 requires the highest degree of cooperation and consolidation, i.e. it represents the most complex realization of logistics chains.

C10. ***Technological and visual integration of logistics systems in urban environment.*** A difference in relation to logistics systems in scenario Sc.1 can be created by constructing modern commercial facilities. On the other hand, in scenarios Sc.2 and Sc.3, logistics solutions and environment can be technologically and visually aligned and brought together.

5. Ranking of Logistics System Scenarios

A combination of fuzzy AHP and VIKOR methods is used in this article to solve the problem of logistics system scenarios ranking. In the literature, there are various examples of the combinations of MCDM methods, in the conventional form or in a fuzzy environment, for solving different problems in the field of logistics: city logistics concept selection (Tadić et al., 2014a), city logistics terminal location selection (Tadić et al., 2012), global logistics strategies identification (Sheu, 2004), solid waste transhipment site selection (Onut and

Soner, 2008), etc. The first part of the model includes the application of the fuzzy AHP method (Van Laarhoven and Pedrycz, 1983), as a fuzzy extension of the conventional AHP method (Saaty, 1980). The first step of the method is the formation of the hierarchical structure of the problem: the ultimate goal on the top, a number of criteria and alternatives at the bottom. For the problem set in this way an analysis is performed in order to determine the relative weights of the criteria at each level, as well as the values of the alternatives, i.e. scenarios, in relation to the criteria. The analysis involves the comparison of all pairs of criteria as well as comparison of all pairs of scenarios with respect to the criteria. A linguistic scale shown in Table 1 which can be converted into triangular fuzzy numbers is used for comparison. In the second part of the model the VIKOR method (Opricović, 1998) is used for the final ranking of scenarios. It determines the compromise solution, i.e. a feasible solution closest to the ideal, and a compromise means an agreement established by mutual concessions.

Table 1
Fuzzy Scale for the Comparison of Criteria/Scenarios

Linguistic term	Fuzzy scales
Absolutely preferable/better (AP/B)	(8, 9, 10)
Very preferable/better (VP/B)	(7, 8, 9)
Strongly preferable/better (SP/B)	(6, 7, 8)
Pretty preferable/better (PP/B)	(5, 6, 7)
Quite preferable/better (QP/B)	(4, 5, 6)
Moderately preferable/better (MP/B)	(3, 4, 5)
Remotely preferable/better (RP/B)	(2, 3, 4)
Barely preferable/better (BP/B)	(1, 2, 3)
Equally important/ good (EI/G)	(1, 1, 2)

The FAHP can be solved using various methods and in this paper the "logarithmic fuzzy preference programming" (LFPP) (Wang and Chin, 2011;

Yu and Shing, 2013) method is used, developed by extending a method of fuzzy preference programming (FPP) (Mikhailov, 2003).

FPP method starts with forming a fuzzy comparison matrix $(\tilde{A})$ elements of which are triangular fuzzy judgments $\tilde{a}_{ij} = \left(l_{ij}, m_{ij}, u_{ij} \right)$ of comparing element *i* in relation to element *j*. Wang and Chin (2011) in LFPP method take logarithm values of fuzzy judgment $\tilde{a}_{ij}$ from matrix $\tilde{A}$ by the following approximate equation:

$$\ln \tilde{a}_{ij} \approx \left(\ln l_{ij}, \ln m_{ij}, \ln u_{ij} \right), \ i, j = 1, 2, \dots, n \quad (1)$$

That is, the logarithm of a triangular fuzzy judgment $\tilde{a}_{ij}$ can be seen as an approximate triangular fuzzy number, whose membership function can be defined as:

$$\mu_{ij}\left(\ln\left(\frac{w_i}{w_j} \right) \right) = \begin{cases} \dfrac{\ln\left(w_i / w_j \right) - \ln l_{ij}}{\ln m_{ij} - \ln l_{ij}}, & \ln\left(\dfrac{w_i}{w_j} \right) \leq \ln m_{ij}, \\[2ex] \dfrac{\ln u_{ij} - \ln\left(w_i / w_j \right)}{\ln u_{ij} - \ln m_{ij}}, & \ln\left(\dfrac{w_i}{w_j} \right) \geq \ln m_{ij}, \end{cases} \quad (2)$$

where $\mu_{ij}\left(\ln\left(w_i / w_j \right) \right)$ is the membership degree of $\ln\left(w_i / w_j \right)$ belonging to the approximate triangular fuzzy judgment $\ln \tilde{a}_{ij} = \left(\ln l_{ij}, \ln m_{ij}, \ln u_{ij} \right)$, and w_i are crisp values of the priority vector

$$W = \left(w_1, \dots, w_n \right)^T > 0, \sum_{i=1}^{n} w_i = 1.$$

It is necessary to find a crisp priority vector to maximize the minimum membership degree $\lambda = \min\left\{ \mu_{ij}\left(h\left(w_i / w_j \right) \right) | i = 1, \dots, n-1; j = i+1, \dots, n \right\}$. The resultant model can be constructed as:

Max λ

$$s.t. \begin{cases} \mu_{ij}\left(\ln\left(w_i / w_j \right) \right) \geq \lambda, i = 1, \dots, n-1; j = i+1, \dots, n, \\ w_i \geq 0, i = 1, \dots, n, \end{cases} \quad (3)$$

or

Max $1 - \lambda$

$$s.t. \begin{cases} \ln w_i - \ln w_j - \lambda \ln\left(m_{ij} / l_{ij} \right) \geq \ln l_{ij}, i = 1, \dots, n-1; j = i+1, \dots, n, \\ -\ln w_i + \ln w_j - \lambda \ln\left(u_{ij} / m_{ij} \right) \geq -\ln u_{ij}, i = 1, \dots, n-1; j = i+1, \dots, n, \\ w_i \geq 0, i = 1, \dots, n. \end{cases} \quad (4)$$

To avoid membership degree λ from taking a negative value, the nonnegative deviation variables δ_{ij} and η_{ij} for *i=1,...,n-1* and *j=1,...,n* are introduced such that they meet the following inequalities:

$$\ln w_i - \ln w_j - \lambda \ln\left(m_{ij} / l_{ij} \right) + \delta_{ij} \geq \ln l_{ij}, i = 1, \dots, n-1; j = i+1, \dots, n,$$
$$-\ln w_i + \ln w_j - \lambda \ln\left(u_{ij} / m_{ij} \right) + \eta_{ij} \geq -\ln u_{ij}, i = 1, \dots, n-1; j = i+1, \dots, n.$$

It is most desirable that the values of the deviation variables are as small as possible. Accordingly the following LFPP-based nonlinear priority model for weight (w_i) derivation for fuzzy AHP is proposed:

$$Min \ J = \left(1 - \lambda \right)^2 + M \cdot \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(\delta_{ij}^2 + \eta_{ij}^2 \right)$$

$$s.t. \begin{cases} x_i - x_j - \lambda \ln\left(m_{ij} / l_{ij} \right) + \delta_{ij} \geq \ln l_{ij}, i = 1, \dots, n-1; j = i+1, \dots, n, \\ -x_i + x_j - \lambda \ln\left(u_{ij} / m_{ij} \right) + \eta_{ij} \geq -\ln u_{ij}, i = 1, \dots, n-1; j = i+1, \dots, n, \\ \lambda, x_i \geq 0, i = 1, \dots, n, \\ \delta_{ij}, \eta_{ij} \geq 0, i = 1, \dots, n-1; j = i+1, \dots, n, \end{cases} \quad (5)$$

where $x_i = \ln w_i$ for *i=1,...,n*, and *M* is a specified sufficiently large constant such as $M = 10^3$.

Let $x_i^* \left(i = 1, \dots, n \right)$ be the optimal solution to model (5). The normalized priorities for fuzzy pair wise comparison matrix $\tilde{A} = \left(\tilde{a}_{ij} \right)_{n \times n}$ can then be obtained as:

$$w_i^* = \frac{\exp\left(x_i^* \right)}{\sum_{j=1}^{n} \exp\left(x_j^* \right)}, i = 1, \dots, n, \quad (6)$$

where $\exp()$ is the exponential function, namely $\exp\left(x_i^* \right) = e^{x_i^*}$ for *i=1,...,n*.

Table 2 shows the fuzzy comparison matrix for obtaining the criteria weights, i.e. the pair wise comparison of criteria using linguistic terms defined in Table 1. In accordance with the described method the nonlinear model (5) is solved and by using Eq. (6) normalized weights of criteria w_j are derived and shown in Table 2.

Table 2

Comparison of Criteria and Final Values of Criteria Weights

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	wi
C1	/	-	-	-	EI	-	RP	QP	RP	QP	0,074
C2	RP	/	-	EI	RP	EI	QP	SP	QP	SP	0,148
C3	QP	RP	/	RP	QP	RP	SP	AP	SP	AP	0,296
C4	RP	-	-	/	RP	EI	QP	SP	QP	SP	0,148
C5	-	-	-	-	/	-	RP	QP	RP	QP	0,074
C6	RP	-	-	-	RP	/	QP	SP	QP	SP	0,148
C7	-	-	-	-	-	-	/	RP	EI	RP	0,037
C8	-	-	-	-	-	-	-	/	-	EI	0,019
C9	-	-	-	-	-	-	-	RP	/	RP	0,037
C10	-	-	-	-	-	-	-	-	-	/	0,019

Comparisons of all pairs of scenarios in relation to the defined criteria by using the linguistic expressions from Table 1 are shown in Table 3. The preference values of scenarios in relation to the criteria are obtained using the LFPP method (Table 4).

Table 3

Comparison of Scenarios in Relation to the Criteria

Scenario	Sc.1	Sc.2	Sc.3	Sc.1	Sc.2	Sc.3	Sc.1	Sc.2	Sc.3	Sc.1	Sc.2	Sc.3	Sc.1	Sc.2	Sc.3
Criterion	C1			C2			C3			C4			C5		
Sc.1	/	-	-	/	-	-	/	BB	MB	/	-	-	/	-	-
Sc.2	MB	/	-	PB	/	-	-	/	RB	RB	/	-	MB	/	-
Sc.3	PB	RB	/	SB	BB	/	-	-	/	MB	BB	/	QB	BB	/
Criterion	C6			C7			C8			C9			C10		
Sc.1	/	-	-	/	-	-	/	-	-	/	BB	RB	/	-	-
Sc.2	QB	/	-	QB	/	-	QB	/	-	-	/	BB	RB	/	-
Sc.3	PB	BB	/	PB	BB	/	PB	BB	/	-	-	/	MB	BB	/

Table 4

Preference Values of Scenarios in Relation to the Criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Sc.1	0,031	0,039	0,627	0,059	0,051	0,044	0,044	0,044	0,571	0,059
Sc.2	0,197	0,320	0,314	0,314	0,316	0,319	0,319	0,319	0,286	0,314
Sc.3	0,772	0,641	0,059	0,627	0,633	0,637	0,637	0,637	0,143	0,627

For the final ranking of the scenarios with the VIKOR method, first it is needed to define the best and worst values of the criterion functions, i.e. to obtain the ideal (f_i^*) and the nadir (f_i^-) solutions (Opricović, 1998):

$$f_i^* = \max_k f_{ki}, k = 1,...,m \qquad (7)$$

$$f_i^- = \min_k f_{ki}, k = 1,...,m \qquad (8)$$

where f_{ki} is the preference value of scenario k in relation to criterion i.

Afterwards, the distances of alternatives from ideal (S_k) and nadir (R_k) solutions are being calculated:

$$S_k = \sum_{i=1}^{n} w_i \left(f_i^{(*} - f_{ki} \right) \Big/ \left(f_i^* - f_i^- \right) \qquad (9)$$

$$R_k = \max_i \left[w_i \left(f_i^{(*} - f_{ki} \right) \Big/ \left(f_i^* - f_i^- \right) \right] \qquad (10)$$

At the end it is necessary to calculate VIKOR values Q_k for $k=1, ..., m$, in the following way:

$$Q_k = v \left[\frac{S_k - S^*}{S^- - S^*} \right] + (1-v) \left[\frac{R_k - R^*}{R^- - R^*} \right] \qquad (11)$$

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 "the maximum group utility ". This means that if v is greater than 0.5, the Q_k index will incline towards the consensus of the majority, and if it is less than 0.5 the Q_k index will incline towards the negative attitude of the majority. For obtaining the values of Q_k, the value $v = 0.55$ is used in this article. The final ranking of the alternatives is obtained by sorting the Q_k values in increasing order. The values S_k, R_k, Q_k, as well as the final ranking of the alternatives are shown in Table 5.

Table 5
The Final Ranking of the Logistics System Scenarios

Scenario	Sk	Rk	Qk	Rank
Sc.1	0,667	0,148	0,550	3
Sc.2	0,566	0,163	0,431	1
Sc.3	0,333	0,296	0,450	2

For a defined set of criteria and their mutual relationships and by using combined FAHP-VIKOR method, Sc.2 is chosen as the best logistics system scenario for the central business district. The same order of scenarios is obtained by using the PROMETHEE method (Tadić and Zečević, 2009), as well as by combining fuzzy AHP and fuzzy TOPSIS methods (Tadić et al., 2014b).

6. Conclusion

MCDM methods provide support to decision-makers (planners, city administration, logistics providers, users, etc.) when selecting the logistics scenario for an urban area, which is performed in this article for the CBDD of Belgrade. Three logistics system scenarios are defined in this article, where scenario Sc.1 involves minimal changes while scenarios Sc.2 and Sc.3 represent modern city logistics solutions. Each of the defined scenarios is a complex logistics system therefore all aspects of their application need to be analyzed for the final decision. Ten criteria are defined for the evaluation of scenarios, and ranking is performed by applying MCDM model that combines FAHP and VIKOR. According to the defined criteria scenario Sc.2 is selected as the most suitable for solving logistics problems of the central city area.

Ranking of logistics system scenarios for the CBD of Belgrade have also been solved by other MCDM methods (Tadić and Zečević, 2009; Tadić et al., 2014b). In all cases, the order of scenarios was the same, but the values for the ranking of alternatives differed. Each method has certain advantages and disadvantages, and they are compared in order to establish a balance between the complexity of implementation and quality of results. Application of some other methods (e.g. ANP, DEMATEL, ELECTRE, etc.) may result in

greater differences between the values based on which the alternatives are being ranked, thereby reducing the risk of making the wrong decisions. However, in some cases, less quality solutions are acceptable, especially if there is no change of the order of alternatives, and on the other hand bring certain savings in time, cost and other resources. This could be the subject of future research.

References

Dablanc, L.; Rakotonarivo, D. 2010. The impacts of logistic sprawl: How does the location of parcel transport terminals affect the energy efficiency of goods' movements in Paris and what can we do about it?, *Procedia - Social and Behavioral Sciences*. DOI: http://dx.doi.org/10.1016/j.sbspro.2010.04.021, 2(3): 6087-6096.

Master plan of Belgrade. 2021. Available from Internet: <http://www.urbel.com/documents/planovi/4231 (sl%20l%2027-03).pdf>.

Mikhailov, L. 2003. Deriving priorities from fuzzy pairwise comparison judgments, *Fuzzy Sets and Systems*. DOI: http://dx.doi.org/10.1016/S0165-0114(02)00383-4, 134(3): 365-385.

Onut, S.; Soner, S. 2008. Transshipment site selection using AHP and TOPSIS approaches under fuzzy environment, *Waste Management*. DOI: http://dx.doi.org/10.1016/j.wasman.2007.05.019, 28(9): 1552-1559.

Opricović, S. 1998. *Multi-criteria optimization of civil engineering systems (in Serbian)*. Faculty of Civil Engineering, University of Belgrade.

Saaty, T.L. 1980. *The Analytic Hierarchy Process*. New York, NY: McGraw-Hill International.

Sheu, J.B. 2004. A hybrid fuzzy-based approach for identifying global logistics strategies, *Transportation Research Part E: Logistics and Transportation Review*. DOI: http://dx.doi.org/10.1016/j.tre.2003.08.002, 40(1): 39-61.

Tadić, S.; Zečević, S. 2009. Selection of the optimal scenario for the logistics system development (in Serbian). In *Proceedings of the Symposium on Operational Research (SYM-OP-IS 2009)*, Ivanjica, 333-336.

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 2012*, Belgrade, Serbia, 345-358.

Tadić, S.; Zečević, S.; Krstić, M. 2014a. A novel hybrid MCDM model based on fuzzy DEMATEL, fuzzy ANP and fuzzy VIKOR for city logistics concept selection, *Expert Systems with Applications*. DOI: http://dx.doi.org/10.1016/j.eswa.2014.07.021, 41(18): 8112-8128.

Tadić, S.; Zečević, S.; Krstić, M. 2014b. Ranking of logistics system scenarios for central business district, *Promet – Traffic&Transportation*, 26(2): 159-167.

Van Laarhoven, P.J.M.; Pedrycz, W. 1983. A fuzzy extension of Saaty's priority theory, *Fuzzy Sets and Systems*. DOI: http://dx.doi.org/10.1016/S0165-0114(83)80082-7, 11(1-3): 229-241.

Wang, Y.M.; Chin, K.S. 2011. Fuzzy analytic hierarchy process: A logarithmic fuzzy preference programming methodology, *International Journal of Approximate Reasoning*. DOI: http://dx.doi.org/10.1016/j.ijar.2010.12.004, 52(4): 541-553.

Yu, J.R.; Shing, W.J. 2013. Fuzzy analytic hierarchy process and analytic network process: An integrated fuzzy logarithmic preference programming, *Applied Soft Computing*. DOI: http://dx.doi.org/10.1016/j.asoc.2012.11.015, 13(4): 1792-1799.

Zečević, S. 2006. *Logistics system development concept for the area of Ada Huja (in Serbian)*. Expert Research, Urban Planning Institute of Belgrade, Belgrade.