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A DESIGN OF SUSTAINABLE LAST-MILE DELIVERY OF POSTAL ITEMS IN CITIES USING MULTI-CRITERIA DECISION-MAKING TECHNIQUES

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Abstract: Transport policy represents a process of regulating and controlling the provision of transport services. In the past, the main emphasis was on the efficient transport connections and safety of drivers and other participants in transportation. These issues are still important and topical; however, due to the enormous increase of vehicles on the streets and harmful gas emissions, noise, congestions, and other negative effects of transportation, some other topics emerged that need to be considered in the design of sustainable development strategies, especially in big cities. This explanation leads to the conclusion that setting a transport policy represents a typical multi-criteria decision-making problem. There are usually certain alternative directions in the design of transport policy that should be assessed by more evaluation criteria, often opposed to each other. This is exactly the problem that is considered in this paper where three concepts of last-mile delivery of postal items are analyzed as the possible directions in the design of transport policy in cities. We applied three multi-criteria decision-making techniques: WASPAS, ARAS, and CoCoSo. The proposed methodology is tested and verified in a real-life case study considering the city of Niš. In the concrete case, the results showed that the best alternative in the design of last-mile delivery activities at the city level is the introduction of inner-city hubs.

Keywords: transport policy, last-mile delivery, postal items, cities, decision-making.

1. Introduction

The transportation sector is one of the crucial fields of economy, which is reflected through its basic aims, connection the places of production and consumption of goods, as well as providing the mobility of people. Such an important activity requires adequate regulating and controlling by the governments. The directions of the transport sector development are generally considered as transport policy. In the past, the main pillars of transport policy were related to effective governance of land use, adequate transport networks, stable funding, and safety of drivers and other participants in transportation (Kennedy *et al.*, 2005). The mentioned issues are still topical; however, due to numerous negative side effects of transport that impact human health and the environment, these topics have taken the leading position in the design of sustainable

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development strategies, especially in big cities (Hysing, 2009; Lazarević *et al.*, 2020).

The significant transportation volumes in cities are generated by the postal and logistics industry. Viu and Alvarez-Palau (2020) emphasized that urban freight logistics is made up of the flow of goods circulating throughout a city. Gonzalez-Feliu *et al*. (2018) stated that an urban transport system can be defined as the set of public-private elements that involve the mobility of people and goods within the urban area. Having in mind significant e-commerce growth in recent years, the demand for last-mile delivery corresponds with this trend. Savelsbergh and Van Woensel (2016) emphasized that the growth in e-commerce had changed the distribution of goods in urban areas. Most of the customers prefer buying products online, simply waiting for the delivery of products to their home or business address. Nevertheless, the national and private postal operators are under the pressure of high-quality expectations by the customers. Additionally, certain nature challenges, such as the Covid-19 pandemic make the process even more complicated.

A design of sustainable transport policy for delivery of postal items is necessary nowadays to achieve more convenient environments for all participants. Ballantyne *et al.* (2013) conducted a study where they investigated how the implementation of some urban freight transport policies have failed due to inefficient participation in the process.

The contemporary strategic directions in the postal sector are also related to green transportation (Memon *et al.*, 2013; Dobrodolac *et al.*, 2016). The set goal can be achieved in various ways and the most often in the literature is to use environmental-friendly transport means and energy (Xiao & Zhou, 2020; Lazarević & Dobrodolac, 2020). However, the phase of the postal process that is the most transportation and cost demanding is the final phase – last-mile delivery (Ralević *et al.*, 2016; Blagojević *et al.*, 2020). Therefore, particular attention should be put here in the process of defining transport policy.

A sustainable last-mile delivery is significantly affected by an appropriate design and location of postal and logistics centers for mail processing (Pamučar *et al.*, 2018a). This is exactly a motive to investigate three alternatives of organizing last-mile delivery in this paper, where the main difference between them is based on different mail processing centers. The first alternative represents a new concept where more smaller postal centers are placed in the city, named inner-city hubs. The second alternative is also a novelty in the postal industry and implies a case where one huge postal center is used for the whole city and all deliveries for the city should start there, regardless of the involved carriers, i.e. courier and postal companies. The third alternative is a traditional case, where each company uses its own postal center, usually constructed at the borders of the city.

The rest of the paper is organized as follows: Section 2 presents the review of the literature. Section 3 describes the methodology. Section 4 is the application of the methodology to the case study. Section 5 concludes the paper.

2. Review of the Literature

There are many methods used to solve complex multi-criteria problems. This section presents the review of the Multi-Criteria Decision-Making (MCDM) techniques in various fields. This paper aims at using the MCDM methods to design sustainable transport policies for postal items delivery. The literature is surveyed on several MCDM methods that should be used in this paper. Those methods are Best-Worst Method (BWM), The Weighted Aggregated Sum Product Assessment (WASPAS), Additive Ration Assessment (ARAS), and Combined Compromise Solution (CoCoSo) method. Since its appearance in the scientific literature, a huge number of applications is noticed. Figure 1 presents the number of publications of those methods with the *h*-index.

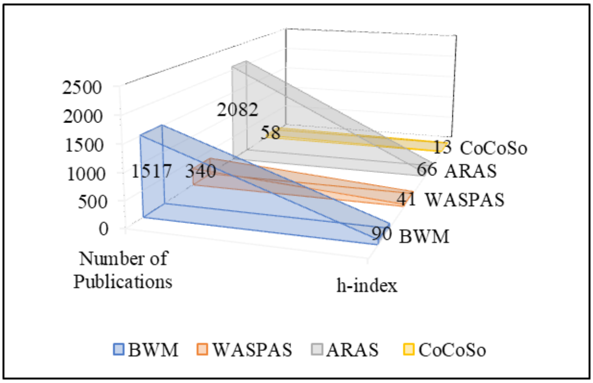

Fig. 1.
Number of Publications in the Literature with h-index

The Best-Worst Method (BWM) is one of the more popular methods nowadays used to support decision-makers when identifying the criteria weights. There are numerous applications of this method. For instance, Ortega *et al.* (2020) applied the BWM to locate a sustainable park and ride facility. Pamučar *et al.* (2020) applied the improved BWM in the field of renewable energy and their ranking. Duleba *et al.* (2021) assessed commuting modal spit. Moslem *et al.* (2020) evaluated the mobility choice after COVID-19 in Italy. Kant and Gupta (2020) assessed the urban freight strategies. Rodríguez-Gutiérez *et al.* (2021) observed small and medium enterprises under sustainability. Ali and Rashid (2020) used the method in the robot selection procedure. Pamučar *et al.* (2018b) utilized this method to find the optimal solution for the fire-fighting helicopters. Majumder *et al.* (2022) applied the extended BWM to water resources.

When it comes to WASPAS method, there are many applications in the scientific literature. Chakraborty and Zavadskas (2014) applied the WASPAS in the manufacturing industry. Karabašević *et al.* (2016) utilized the WASPAS in personnel selection. Ghorabaee *et al.* (2016) evaluated green suppliers. Jayant *et al.* (2018) selected the best 3PL provider. Ilbahar and Kahraman (2018) measured the performance of a retail store. Mesran *et al.* (2020) ranked teacher performance. Yörükoğlu and Aydın (2020) evaluated digital library. Mic and Antmen (2021) applied the WASPAS to select the best university location. Simić *et al.* (2021) assessed the best last-mile delivery mode in Belgrade.

Since the ARAS method had been introduced, numerous applications can be found in the scientific literature. Zavadskas and Turskis (2010) applied the ARAS to solve the micro-climate problem in offices. Keršulienė and Turskis (2014) selected personnel. Stanujkić (2015) evaluated websites. Zavadskas *et al*. (2015) evaluated and selected the seaport location. Jovčić *et al.* (2020) selected the best freight distribution concept.

Regarding the CoCoSo method, there are numerous applications in various spheres, such as electric vehicle selection (Biswas *et al*., 2019), sustainable supplier selection (Ecer and Pamučar, 2020), logistics center location (Ulutaş *et al*., 2020), personnel selection (Popović, 2021), etc.

Based on the review of the literature, it can be concluded that the investigated MCDM methods have huge popularity and possible implementation in many areas. In this paper, we apply the BWM, WASPAS, ARAS and CoCoSo to design a sustainable transport policy for postal items delivery.

3. Methodology

This section describes the methodology applied in this paper to rank the alternatives. The Best-Worst Method (BWM) is used to obtain the criteria weights, which are further used in a decision-making process. The Weighted Aggregated Sum Product Assessment (WASPAS), Combined Compromise Solution (CoCoSo), and Additive Ration Assessment (ARAS) methods are used in the final ranking of alternatives.

3.1. Best-Worst Method (BWM)

The Best-Worst method belongs to the MCDM methods and it is used for obtaining the criteria weights. The BWM is developed by Rezaei (2015). Rezaei (2015) emphasized that when executing a pairwise comparison a_{ij}, the decision-maker expresses both the direction and the strength of the preference *i* over *j*. According to Rezaei (2015) the Best-Worst Method is described through the following steps:

Step 1. Determine the evaluation criteria.

In this step, the criteria $\{c_1, c_2, \ldots c_n\}$ that should be used to evaluate a decision are considered.

Step 2. Identify the best (most important) and the worst (less important) criterion.

If more than one criterion is the best or the worst, one can be chosen arbitrary. In this step, the decision-maker identifies the best and the worst criteria in general, and no comparison is made at this stage.

Step 3. Determine the preference of the best criterion over all the other criteria using a scale of 1 to 9. The resulting Best-to-Others vector should be:

$$A_B = (a_{B1}, a_{B2,\ldots} a_{Bn}) \quad (1)$$

Where a_{Bj} indicates the preference of the best criterion *B* over criterion *j*. It is clear that $a_{BB} = 1$.

Step 4. Determine the preference of all the criteria over the worst criterion using a number between 1 and 9. The Others-to-Worst vector should be:

$$A_w = (a_{1w}, a_{2w,\dots} a_{nw})^T \quad (2)$$

Where a_{jw} presents the preference of the criterion j over the worst criterion W. It is clear that $a_{ww} = 1$.

Step 5. Obtain the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$

The optimal weight for the criteria is the one where for each pair of W_B/W_j and W_j/W_w, we have $W_B/W_j = a_{Bj}$ and $W_j/W_w = a_{jw}$. To satisfy these conditions for all j, we should find a solution where the maximum absolute differences $\left|\frac{W_B}{W_j} - a_{Bj}\right|$ and $\left|\frac{W_j}{W_w} - a_{jw}\right|$ for all j is minimized. Considering the non-negativity and sum condition for the weights, that would lead to the following *minmax* problem:

$$min \max_j \left\{\left|\frac{W_B}{W_j} - a_{Bj}\right|, \left|\frac{W_j}{W_w} - a_{jw}\right|\right\} \quad (3)$$

s.t.

$$\textstyle\sum_j W_j = 1; W_j \geq 0 \text{ for all } j.$$

After Equation 3, the problem can be transformed into linear programming: Min ξ

s.t.

$$\left|\frac{W_B}{W_j} - a_{Bj}\right| \leq \xi, \text{ for all } j.$$
$$\left|\frac{W_j}{W_w} - a_{jw}\right| \leq \xi, \text{ for all } j. \quad (4)$$

$$\textstyle\sum_j W_j = 1 ; W_j \geq 0 \text{ for all } j.$$

The optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$ and ξ^* are obtained by solving Equation 4.
The consistency ratio of the model is calculated using the following equation:

$$Consistency\ Ratio = \frac{\xi}{CI}; \quad (5)$$

where ξ is the optimal objective value of Equation (5), and CI is the consistency index which can be utilized from Table 1.

Table 1
Table of the Consistency Index

a_{Bw}	1	2	3	4	5	6	7	8	9
Consistency index max(ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Source: (Rezai, 2015)

3.2. Weighted Aggregated Sum Product Assessment (WASPAS) Method

Weighted Aggregated Sum Product Assessment (WASPAS) method belongs to the multi-criteria decision-making methods (MCDM) used in ranking alternatives and is introduced by Zavadskas *et al.* (2012). This MCDM method couples the Weighted Sum Model (WSM) and Weighted Product Model (WPM) for the decision-making process. The WASPAS method should be described through several steps:

Step 1. Obtain linear normalization of performance values.

To obtain linear normalization of performance values, it is necessary to apply Equation 6:

$$\bar{x}_{ij} = \begin{cases} \frac{x_{ij}}{max_i x_{ij}} \ if \ j \epsilon \ B; \\ \frac{min_i x_{ij}}{x_{ij}} \ if \ j \in N; \end{cases} \quad (6)$$

where: B and$N$ represent the sets of beneficial and non-beneficial criteria, respectively.

Step 2. Calculate the measures of WSM $Qi^{(1)}$ and WPM $Qi^{(2)}$ for each alternative (Equation 7 and Equation 8):

$$Q_i^{(1)} = \sum_{j=1}^{m} W_j \cdot \bar{x}_{ij}; \quad (7)$$

$$Q_i^{(2)} = \prod_{j=1}^{m} (\bar{x}_{ij})^{W_j}; \quad (8)$$

Step 3. Calculate the aggregated measure of the WASPAS method for each alternative as follows (Equation 9).

$$Q_i = \lambda Q_i^{(1)} + (1 - \lambda) \, Q_i^{(2)}; \quad (9)$$

where: λ is the parameter of the WASPAS method and could be changed in the range of 0 to 1. When $\lambda = 1$, the WASPAS method is transformed to WSM, and $\lambda = 0$ leads to WPM model.

3.3. The Additive RAtio Assessment (ARAS) Method

The Additive Ratio Assessment (ARAS) method is developed by Zavadskas and Turskis (2010). This method is to be used in cases where multiple criteria are considered in a decision-making process. Zavadskas and Turskis (2010) described the ARAS method through the following steps:

Step 1. Formulate an initial decision-making matrix.

The initial decision-making matrix includes m alternatives compared on n criteria

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}; i = \overline{0,m}, j = \overline{1,n}; \quad (10)$$

where: m - number of alternatives, n – number of criteria, x_{ij} –the performance value of the i–th alternative in terms of the j-th criterion, x_{0j} – optimal value of j-th criterion.

If the optimal value of j-th criterion is unknown, then there is necessary to apply Equation 11:

$$\begin{aligned} x_{0j} &= max_i x_{ij}, \text{ if } max_i x_{ij} \text{ is preferable,} \\ x_{0j} &= min_i x_{ij}^{*}, \text{ if } min_i x_{ij}^{*} \text{ is preferable.} \end{aligned} \quad (11)$$

Step 2. Normalize the Input Data.

The initial decision-making matrix is normalized – defining values $\overline{x_{ij}}$.

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix}; i = \overline{0,m}, j = \overline{1,n}; \quad (12)$$

For the criteria with the maximal preferences, the normalization is calculated by Equation 13:

$$\overline{x_{ij}} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}; \quad (13)$$

For the criteria with the minimal preferences, the normalization is obtained through two steps, by Equation 14:

$$x_{ij} = \frac{1}{x_{ij}^{*}}; \overline{x_{ij}} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}; \quad (14)$$

Step 3. Calculate Normalize-Weighted Matrix - $\hat{X}$.

The values of weight Wj are usually obtained by the experts' judgment. The sum of weights Wj is limited to 1:

$$\sum_{j=1}^{n} w_j = 1; \quad (15)$$

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \cdots & \hat{x}_{0j} & \cdots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}; i = \overline{0,m}, j = \overline{1,n}; \quad (16)$$

The Normalize-weighted numbers of all the criteria are computed by applying Equation 17:

$$\hat{x}_{ij} = \bar{x}_{ij} \cdot \mathrm{W_j}; i = \overline{0,m}; \quad (17)$$

where Wj is the importance of the *j-th* criterion and $\bar{x}_{ij}$ is the normalized rating of the *j-th* criterion.

Step 4. Find the value of the optimality function.

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}; \; i = \overline{0,m}; \quad (18)$$

where: S_i is the value of optimality function of i-th alternative

The highest value of S_i is the best one, while the lowest one is the worst. Therefore, the greater the value of the optimality functionS_i, the stronger preference of the alternative. The priorities of alternatives can be determined according to the value S_i.

Step 5. Calculate the degree of the alternative utility.

To calculate the degree of the alternative utility, the variants should be compared with the ideally best one S_0. The calculation of the utility degree K_i of an alternative a_i is obtained by Equation 19:

$$K_i = \frac{S_i}{S_0}; i = \overline{0,m}; \quad (19)$$

where S_i and S_0 are the optimality criterion values. The calculated values K_i should be between 0 and 1.

3.4. Combined Compromise Solution (CoCoSo) Method

A Combined Compromise Solution (CoCoSo) Method was introduced by Yazdani *et al.* (2019). The CoCoSo method is based on aggregation strategies. A distance measure is considered, which originates from the grey relational coefficient and targets to enhance the flexibility of the results. The CoCoSo method is coupling the Simple Additive Weighting (SAW) method and Exponentially Weighted Product (EWP) method. Yazdani *et al.* (2019) explained the CoCoSo method through the following steps:

Step 1. Determine the Initial Decision-Making Matrix (IDMM).

$$X = \begin{bmatrix} x_{11} & \cdots & x_{12} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{21} & \cdots & x_{22} & \cdots & x_{2n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}, i = 1,2,\dots,m, j = 1,2,\dots,\mathrm{n}; \quad (20)$$

Step 2. Normalize the IDMM.

Two equations are utilized in this step, depending on the criteria type. If the criterion is a beneficial (B), there is Equation 21 for normalization:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, i = 1,2,\dots,m, j = 1,2,\dots,\mathrm{n}; \quad (21)$$

If the criterion is non-beneficial i.e., cost (C), there is the following equation for normalization:

$$r_{ij}=\frac{\max_i x_{ij}-x_{ij}}{\max_i x_{ij}-\min_i x_{ij}}, i = 1,2,\dots,m, j = 1,2,\dots,n; \quad (22)$$

Step 3. Calculate the Weighted Sequences S_i and P_i for each alternative.

$$S_i = \sum_{j=1}^{n}(w_j \cdot r_{ij}), i = 1,2,\dots,m; \quad (23)$$

$$P_i = \sum_{j=1}^{n}(r_{ij})^{w_j}, \ i = 1,2,\dots,m; \quad (24)$$

Step 4. Calculate the Total Utility Strategies for each alternative.

The first strategy of Total Utility (K_{ia}) expresses the arithmetic mean of the sum of S_i and P_i values:

$$K_{ia} = \frac{P_i+S_i}{\sum_{i=1}^{m}(P_i+S_i)}, i = 1,2,\dots,m; \quad (25)$$

The second strategy of Total Utility (K_{ib}) expresses the sum of the relative relations S_i and P_i with their worst values:

$$K_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i}, i = 1,2,\dots,m; \quad (26)$$

The third strategy of Total Utility (K_{ic}) expresses a balanced compromise of S_i and P_i values:

$$K_{ic} = \frac{\lambda S_i+(1-\lambda)P_i}{(\lambda \max_i S_i+(1-\lambda)\max_i P_i)}, 0 \le \lambda \le 1; \quad (27)$$

Step 5. Obtain the final rank of alternatives.

The final ranking of the alternatives is determined based on K_i:

$$K_i = (K_{ia} \cdot K_{ib} \cdot K_{ic})^{\frac{1}{3}}+\frac{1}{3}(K_{ia} + K_{ib}+K_{ic}); \quad (28)$$

4. Application of the Proposed Methodology to a Case Study

This section presents the application of the proposed methodology to the case study. A subject of a case study is the city of Niš. Niš is a city with a very rich history, one of the oldest in Europe and the Balkans. Having in mind the geopolitical status, the city was considered as a link between the East and the West. Niš is the third-largest city in Serbia and the administrative center of the Nišava District in southern Serbia (Figure 2). The inner city has a population of 183,164, while its administrative area has a population of 260,237 inhabitants. In the 12th century, it was the capital of Serbia during the reign of Stefan Nemanja. Once again, Niš became the capital and a host for Serbian Government and National Assembly in World War I. Today, Niš is one of the pillars of the Serbian economy and culture.

In this paper, we examine the possibility to introduce a new concept of postal items delivery in the city of Niš. The first alternative implies an introduction of smaller hubs all over the city that would be responsible for the preparation of mail for last-mile delivery. Since these kinds of centers are more close to the final destination, this means that different transport means in the last-mile delivery should be used compared to the traditional concept. The new transport means would allow the use of bicycles and other means with lower capacities. This is especially convenient in cities with a plain terrain, such is the case in the city of Niš (Figure 3). A characteristic of these small centers would be that they could be used by different postal and logistics companies. In this paper, we named them the Inner City Hubs (ICH) and we consider them as the alternative number 1.

The second proposed innovation relates to the introduction of a new huge processing center where all postal companies would be obliged to start their last-mile deliveries from that point. An idea for this concept came from the fact that sometimes, the delivery vehicles of different carriers can be seen at the same location or same street at the same moment of time. This leads to the conclusion that the routing of these vehicles could be significantly improved if this would be managed from a centralized point. The losses in the costs, as well as in the environmental field, are particularly evident in big cities where the traffic congestions are usual, such as the case of the city of Niš, where almost all central streets are with slow traffic because of a high number of vehicles on the streets (Figure 4). This concept is named here as United Consolidation Center (UCC) and represents the alternative number 2.

The third alternative is the traditional concept. It means each postal company has its own postal and logistics center for mail processing that is usually placed on the borders of a city. This is alternative number 3 in our case. Therefore, the list of considered alternatives is the following:

- A_1 – Inner City Hubs,
- A_2 – United Consolidation Center,
- A_3 – Traditional Concept.

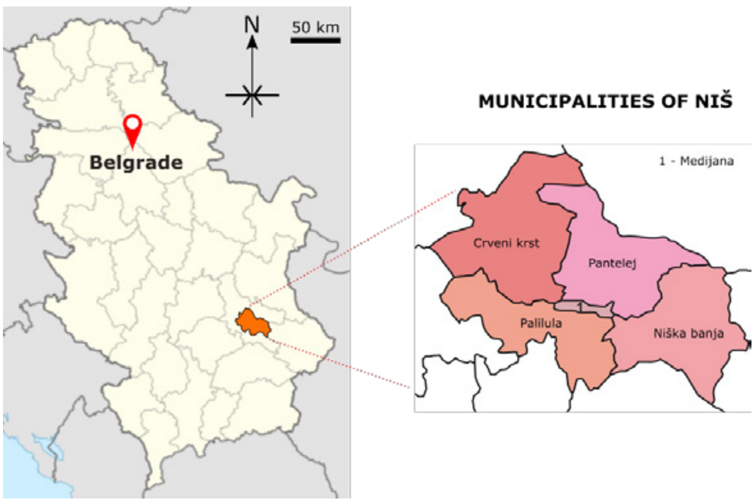

Fig. 2.
The Municipalities of Niš

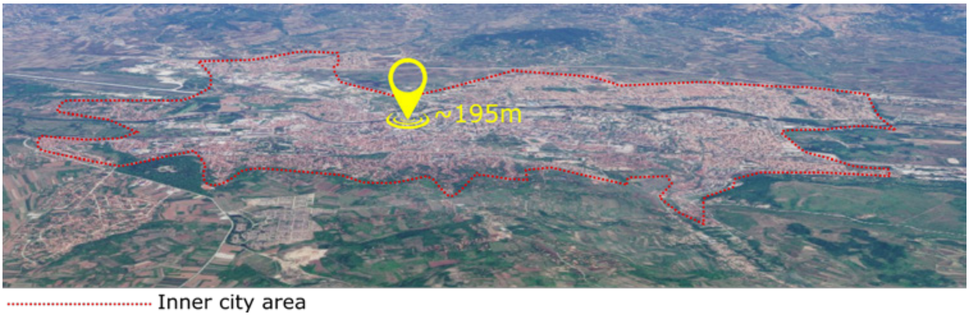

Fig. 3.
The Relief of Niš

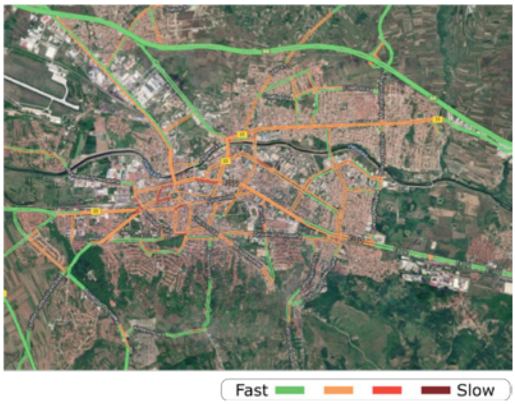

Fig. 4.
The Main Traffic Flows in Niš

These alternatives should be evaluated by certain criteria. In this research, we consider the following criteria, according to the opinion of contacted experts:

- *Investment cost* (C_1) – Cost related to the introduction of the alternative last-mile delivery concept. It is clear that the construction of a new huge consolidation center would lead to the highest costs.
- *Legal limitations* (C_2) – There is a question of the legal compatibility of the proposed last-mile delivery concepts and legal acts. For example, forcing all delivery companies to use the same facility for processing mail may be subject to competition laws and should be further examined.
- *Congestion generation* (C_3) – A traffic congestion is a common phenomenon in cities. As previously explained, the traditional concept has the highest potential for contributing to traffic congestion. If all deliveries in a city would be centralized, the state in this field would be certainly improved. Further, if alternative transport means that use separate paths would be introduced, such as cargo bicycles, this would, even more, reduce the congestion.

- *Noise pollution* (C_4) The impact on noise is significant since last-mile delivery is realized in populated places in different parts of the day. Last-mile delivery organized by transport means of lower capacity would certainly contribute to lower noise.
- *Harmful gas emissions* (C_5) – The environmental impact of last-mile delivery is reflected also through the level of harmful air emissions exhausted during delivery. The traditional concept may be considered as the worst in this field because it implies the highest level of vehicles on the streets, as well as the vehicles with higher capacities.
- *Infrastructure convenience* (C_6) – This criterion explains how convenient is to introduce a certain delivery concept from the standpoint of requested infrastructure. For example, the alternatives that imply the use of havier vehicles request better roads and infrastructure.

To obtain the input data for the decision-making process, we contacted five experts from the field of postal services. They assessed the values of criteria per each alternative on the scale from 1 to 10, where all criteria, except C_6, were of min type, which means that lower grade explains the alternative as more appropriate. The input matrix data with the criteria weights for a decision-making process is presented in Table 2.

Table 2

Input Decision-Making Matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	4	2	1	2	2	10
A_2	10	10	6	7	8	6
A_3	2	1	10	10	10	6
Weights	0.0349	0.1099	0.1466	0.2199	0.3421	0.1466
min-max	min	min	min	min	min	max

After the WASPAS method is applied, the results are presented in the following Tables (Table 3 – Table 6).

Table 3

Input Decision-Making Matrix (DMM) with the Criteria Weights

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	4	2	1	2	2	10
A_2	10	10	6	7	8	6
A_3	2	1	10	10	10	6
Weights	0.0349	0.1099	0.1466	0.2199	0.3421	0.1466
	min	min	min	min	min	max
	2	1	1	2	2	10

Table 4

Normalization of the Input DMM and Weighted Product Values

Normalization	C_1	C_2	C_3	C_4	C_5	C_6	Weighted Product Method
A_1	0.50000	0.5000	1.0000	1.0000	1.0000	1.0000	5.9028
A_2	0.20000	0.1000	0.1667	0.2857	0.2500	0.6000	4.8002
A_3	1.00000	1.0000	0.1000	0.2000	0.2000	0.6000	4.9199

Table 5

Calculated SAW Values

Weighted DM matrix	C_1	C_2	C_3	C_4	C_5	C_6	Simple Additive Weighting Method (SAW)
A_1	0.01745	0.0550	0.1466	0.2199	0.3421	0.1466	0.92760
A_2	0.00698	0.0110	0.0244	0.0628	0.0855	0.0880	0.27872
A_3	0.03490	0.1099	0.0147	0.0440	0.0684	0.0880	0.35982

Table 6

Final Ranking of Alternatives

WHEN λ is 1	A_1	**0.92760**
	A_2	0.27872
	A_3	0.35982

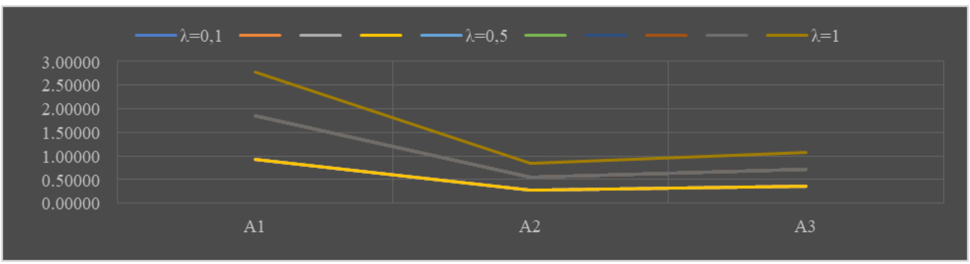

Fig. 5.

Final Rank WASPAS

As it can be seen in Table 6, the WASPAS method shows that the alternative A_1 received the best scores in the case of the city of Niš. This is even confirmed in the sensitivity analysis where parameter λ was changed (Figure 5). When the ARAS method is applied, the following results are obtained (Table 7 - Table 9) and presented in Figure 6.

Table 7
The Initial Decision-Making Matrix

Initial Matrix	C_1	C_2	C_3	C_4	C_5	C_6
0 - Optimal Value	2	1.00	1.00	2.00	2.00	10.00
A_1	4	2	1	2	2	10
A_2	10	10	6	7	8	6
A_3	2	1	10	10	10	6
min/max	**min**	**min**	**min**	**min**	**min**	**max**
sum	1.3500	2.6000	2.2667	1.2429	1.2250	32.0000

Table 8
Normalization of the Input Data with Criteria Weights

Normalization	C_1	C_2	C_3	C_4	C_5	C_6
0	0.3704	0.3846	0.4412	0.4023	0.4082	0.3125
A_1	0.1852	0.1923	0.4412	0.4023	0.4082	0.3125
A_2	0.0741	0.0385	0.0735	0.1149	0.1020	0.1875
A_3	0.3704	0.3846	0.0441	0.0805	0.0816	0.1875
min/max	**min**	**min**	**min**	**min**	**min**	**max**
Weights	0.0349	0.1099	0.1466	0.2199	0.3421	0.1466

Table 9
Weighted Normalized Data

Weighted Matrix	C_1	C_2	C_3	C_4	C_5	C_6	S	K	Rank
0	0.0129	0.0423	0.0647	0.0885	0.1396	0.0458	0.3938		
A_1	0.0065	0.0211	0.0647	0.0885	0.1396	0.0458	0.3662	0.9299	1
A_2	0.0026	0.0042	0.0108	0.0253	0.0349	0.0275	0.1053	0.2673	3
A_3	0.0129	0.0423	0.0065	0.0177	0.0279	0.0275	0.1348	0.3422	2
min/max	**min**	**min**	**min**	**min**	**min**	**max**			**0.8510**

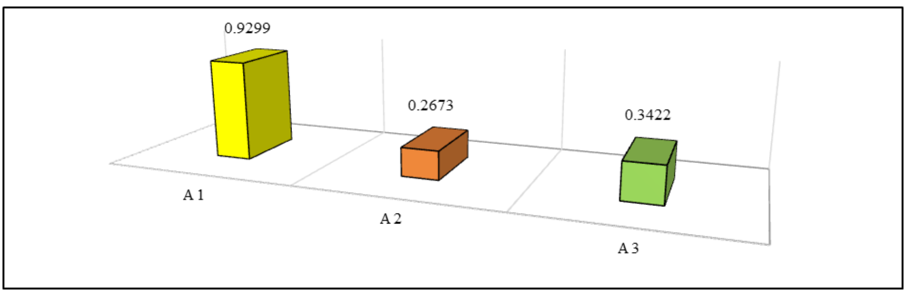

Fig. 6.
Final Rank ARAS

According to the ARAS method, alternative 1 was ranked the best, followed by alternative 3 and alternative 2. This confirms the results obtained by the WASPAS method.

When the CoCoSo method was applied, the results were presented in the following Tables (Table 10 - Table 13).

Table 10

The Initial Decision-Making Matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	4	2	1	2	2	10
A_2	10	10	6	7	8	6
A_3	2	1	10	10	10	6
	2	1	1	2	2	10
	10	10	10	10	**10**	**6**
Weights	0.0349	0.1099	0.1466	0.2199	0.3421	0.1466
	min	min	min	min	min	max

Table 11

Normalization of the Input Data

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.7500	0.8889	1.0000	1.0000	1.0000	1.0000
A_2	0.0000	0.0000	0.4444	0.3750	0.2500	0.0000
A_3	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Weights	0.0349	0.1099	0.1466	0.2199	0.3421	0.1466

Table 12

Obtained Si and Pi Values

	C_1	C_2	C_3	C_4	C_5	C_6	**Si**	**Pi**	**SiPi**
A_1	0.0262	0.0977	0.1466	0.2199	0.3421	0.1466	0.9791	5.9771	6.9562
A_2	0.0000	0.0000	0.0652	0.0825	0.0855	0.0000	0.2331	2.3163	2.5494
A_3	0.0349	0.1099	0.0000	0.0000	0.0000	0.0000	0.1448	2.0000	2.1448
						min	0.1448	2.0000	11.6504
						max	0.9791	5.9771	

Table 13

Total Utility Strategies and Final Rank

Kia	**Kib**	**Kic**	**Rank**
0.5971	9.7501	1.0000	1.4936
0.2188	2.7682	0.3665	0.5069
0.1841	2.0000	0.3083	0.4085

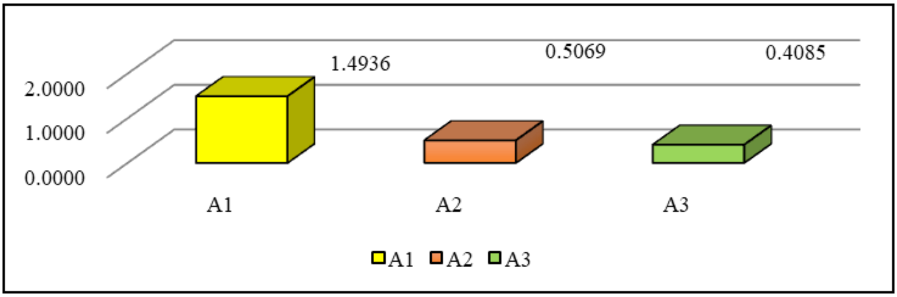

Fig. 7.
Final Rank of the Alternatives

The comparative analysis among the implemented methods is performed and presented in Table 14.

Table 14
Comparative Analysis

	WASPAS	CoCoSo	ARAS
A1	1.4936	0.9276	0.9299
A2	0.5069	0.2787	0.2673
A3	0.4085	0.3598	0.3422

It can be noticed that alternative 1 was ranked best according to all those methods. The CoCoSo and ARAS methods ranked the alternative 3 as second best, while according to the WASPAS, alternative 2 was ranked second best. The results of the comparative analysis are presented in Figure 8.

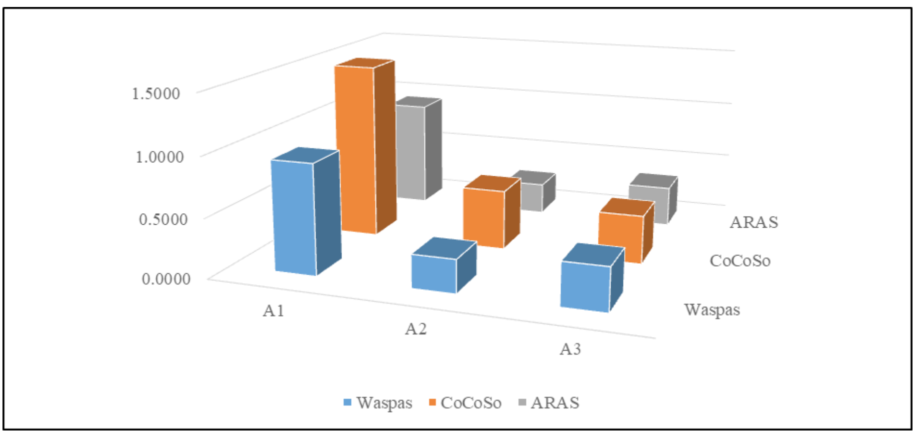

Fig. 8.
Comparative Analysis

5. Conclusion

Transport policy in today's society needs to be based on environmental principles as one of the main pillars. Modern cities are overcrowded with vehicles and harmful gas emissions, noise, congestions, and other negative effects of transportation are unavoidable. However, these effects can be reduced to some extent by adequate human knowledge in defining transportation processes.

In this paper, we compared three approaches to defining the concept of last-mile delivery. The first alternative represents a case with inner-city hubs placed all over the city. In the second alternative, a huge postal center should be constructed where all deliveries for the city should start there. The third alternative is a traditional case, where each company uses its own postal center.

We applied three multi-criteria decision-making techniques: WASPAS, ARAS, and CoCoSo to investigate which alternative is the most appropriate in a chosen case study – the city of Niš. The proposed methodology showed that, in the concrete case, the best alternative is the introduction of inner-city hubs for last-mile delivery activities. This conclusion is confirmed by all three implemented decision-making techniques. A recommendation for further research would be to examine the feasibility and limitations for introductions of this concept in a reality, where all stakeholders should be contacted and interviewed, from the city authorities to the participating delivery companies.

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