LAST-MILE DELIVERY (LMD) MODE SELECTION USING A MULTI-CRITERIA DECISION-MAKING APPROACH

Ivana Nikolić [a], Marijana Petrović [a], Stefan Jovčić [b], Momčilo Dobrodolac [a,*]

[a] University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia
[b] University of Pardubice - Faculty of Transport Engineering, Czech Republic

---

Abstract: *Last-Mile Delivery (LMD) is the final and one of the most demanding steps in urban logistics distribution. In a modern, information society, e-commerce is one of the most significant generators of LMD volumes. Having in mind its exponential growth in recent years, the task to organize efficient LMD is more and more demanding. This paper aims at solving the LMD mode selection problem. Since there are several possibilities considering the LMD in cities around the world, there is a question about which mode to choose in a concrete case. In this paper, a Combined Compromise Solution Method (CoCoSo) is used to select the most appropriate LMD mode in the capital of Serbia - Belgrade. Five possible LMD modes are considered such as Traditional, Cargo Bikes, Public Transport, Electric Vehicles, and Drones. The applicability of the CoCoSo method is demonstrated in an illustrative example, and the experts' opinions are included. The result of the CoCoSo method ranks the alternatives from best to worst.*

Keywords*: last-mile delivery, CoCoSo, transport mode.*

---

1. INTRODUCTION

Last-Mile Delivery (LMD) is an essential part of city logistics and postal processes. The main aim of the city logistics is organizing, managing, and monitoring the delivery of shipments to the final users in the territory of the city. According to Dablanc (2017), the notion of city logistics is specified as any delivery of services contributing to effectively managing the circulation of goods in cities and providing inventive reactions to customer requirements. Since the customers' demands and expectations are increasing over time, especially in urban areas, the managers of the distribution companies face constantly new problems related to LMD. In addition, globalization, as well as the rapid development of e-commerce, have caused increased transport, especially in urban areas. According to Ranieri et al. (2018), due to globalization and the increased e-commerce activities,

* m.dobrodolac@sf.bg.ac.rs

products can be acquired everywhere, shipments travel all over the globe and the vast majority of the shipments are delivered in cities. World Economic Forum estimates that by 2030 last-mile service in urban areas will increase by 78% (WEF, 2020).

The rapid development of the Internet, as well as online shopping, allows people in both rural and urban areas to move as little as possible and to simply receive their shipments to their address. Here is the need for the organization of logistics activities in the city, which is not an easy task for shipment companies. The reason is simple, cities suffer from traffic congestion, there are too many shipments, different user requirements and expectations, etc. It can also be pointed out that the companies that distribute shipments to end-users are under enormous pressure. Good organization, as well as coordination of all distribution activities, can greatly increase the percentage of satisfied customers, reduce costs, save time and thus be ahead of the competition.

The organization of LMD can be also affected by some other factors, such as pandemic circumstances. For example, when the COVID-19 pandemic started, due to reduced access to physical shops and the lower mobility of consumers, the e-commerce market significantly increased (Figure 1). The year-on-year (YoY) change in the number of online orders illustrates a marked growth with respect to the year 2019. Such huge changes represent a demanding task for postal and logistic companies to deliver the ordered retail goods to customers.

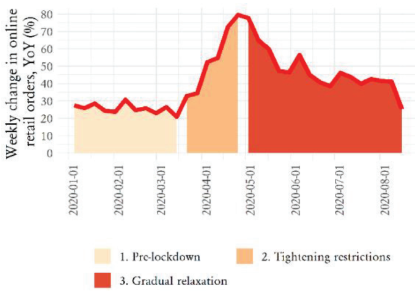

Figure 1. YoY evolution of global e-commerce orders (Source: UPU, 2021)

Previously explained forces managers of the postal and logistics companies to constantly improve the technological process in their companies. One of these issues relates to transport mode selection. In this paper, we consider the LMD mode selection problem in the context of Belgrade, Serbia. We used a Combined Compromise Solution - CoCoSo method (Yazdani and Chatterjee, 2018; Yazdani et al., 2019). The added value of CoCoSo is in combining compromise perspectives with the aim to reconcile conflicting evaluation criteria. At the same time, a selection of LMD mode includes multiple, and often conflicting, performance criteria like time (deprivation), cost, coverage, equity, and security (Ferrer et al., 2018). The five alternatives as possible solutions are considered: Traditional, Cargo Bikes, Public Transport, Electric Vehicles, and Drones. These five alternatives are compared according to six evaluation criteria.

This paper is structured in the following way: Section 2 is the review of the literature based on CoCoSo applications. Section 3 is the description of the methodology. Section 4 is the application of the methodology, an illustrative example in the context of Belgrade, the capital of Serbia. Section 5 offers the managerial implications, while Section 6 gives some concluding remarks.

2. LITERATURE REVIEW

This section presents a summary of the available applications of the CoCoSo method and its extension in various fields. CoCoSo is a relatively new MCDM method with growing popularity among researchers (Figure 2). Since it was introduced by Yazdani and Chatterjee (2018) it has been applied in various fields dealing with the selection of the best alternative under numerous conflicting criteria.

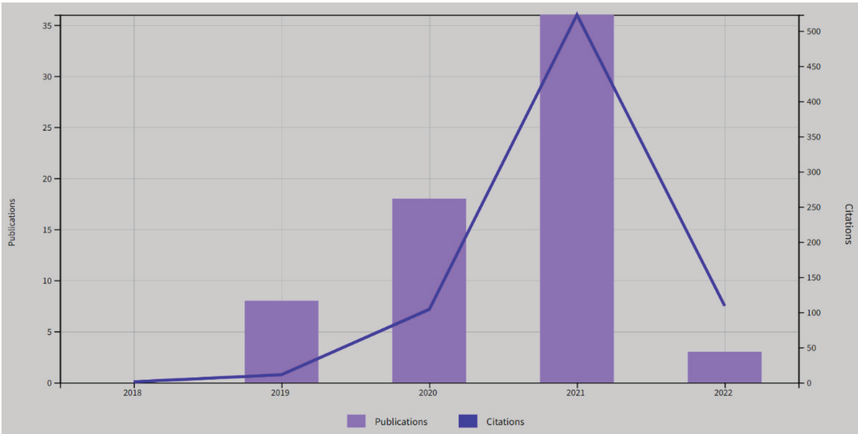

Figure 2. Number of publications and citations of the CoCoSo method (Source: WoS)

For example, Yazdani and Chatterjee (2018) applied this method in the technology selection in the manufacturing industry. Biswas et al. (2019) evaluated and selected electric vehicles. Ecer and Pamučar (2020) evaluated and selected sustainable suppliers. Hashemkhani Zolfani et al. (2020) investigated a temporary hospital location. Ulutaş et al. (2020) searched for the best logistics center location. Peng and Smarandache (2020) evaluated China's rare earth industry security by the CoCoSo. Recently, Popović (2021) applied the CoCoSo in the personnel selection process. Mandal et al. (2022) used the CoCoSo to select a cloud service provider. Turskis et al. (2022) applied the method in the civil engineering industry. The CoCoSo method is also used for LMD mode selection in the case of Pardubice, Czech Republic (Švadlenka et al., 2020).

As may be noticed from the literature review, the application of the CoCoSo method can be found in various fields such as manufacturing, automotive industry, logistics, human resources, civil engineering, etc. Following the recent application for the LMD mode selection problem (Švadlenka et al., 2020), in this paper, the CoCoSo method is used in the case of Belgrade, Serbia. The next section is the elaboration of the CoCoSo method.

3. METHODOLOGY - COMBINED COMPROMISE SOLUTION (COCOSO) METHOD

This section presents a step-by-step method used to solve the Last-Mile Delivery (LMD) mode selection problem. A Combined Compromise Solution (CoCoSo) method is utilized to solve the LMD mode selection problem. This method is proposed by Yazdani and Chatterjee (2018) and belongs to multi-criteria decision-making methods. The CoCoSo method is based on an integrated Simple Additive Weighting (SAW) method and

Exponentially Weighted Product (EWP) model. Yazdani et al. (2019) described the CoCoSo method through the following steps:

Step 1. The initial decision-making matrix with the input data

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

Step 2. Normalize the input data

The normalization depends on the type of criteria. if the criterion is a beneficial (B), the following equation for normalization is applied:

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

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

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, i = 1,2,\ldots,m, j = 1,2,\ldots,\mathrm{n}; \quad (3)$$

Step 3. Obtain the Weighted Sequences S_i and P_i for all alternatives

$$S_i = \sum_{j=1}^{n} (w_j \cdot r_{ij}), i = 1,2,\ldots,m; \quad (4)$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j},\ i = 1,2,\ldots,m; \quad (5)$$

Step 4. Compute the three Total Utility Strategies for all alternatives

The first strategy of total utility (K_{ia}) is the arithmetic mean of the sum of S_i and P_i values:

$$K_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)}, i = 1,2,\ldots,m; \quad (6)$$

The second strategy of total utility (K_{ib}) is the sum of the relative relations S_i and P_i with their worst values:

$$K_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i}, i = 1,2,\ldots,m; \quad (7)$$

The third strategy of total utility (K_{ic}) is a balanced compromise of S_i and P_i values:

$$K_{ic} = \frac{\lambda S_i + (1-\lambda) P_i}{(\lambda \max_i S_i + (1-\lambda) \max_i P_i)}, 0 \le \lambda \le 1; \quad (8)$$

Step 5. Obtain the final ranking of alternatives

The final ranking of the alternatives K_i is calculated by applying Equation (9):

$$K_i = (K_{ia} \cdot K_{ib} \cdot K_{ic})^{\frac{1}{3}} + \frac{1}{3} (K_{ia} + K_{ib} + K_{ic}); \quad (9)$$

4. CASE STUDY

The previously described CoCoSo method is demonstrated in the case of Belgrade, the capital of Serbia. Its position, as well as relief, are illustrated in Figure 3 and Figure 4.

Figure 3. Position of the capital city of Serbia

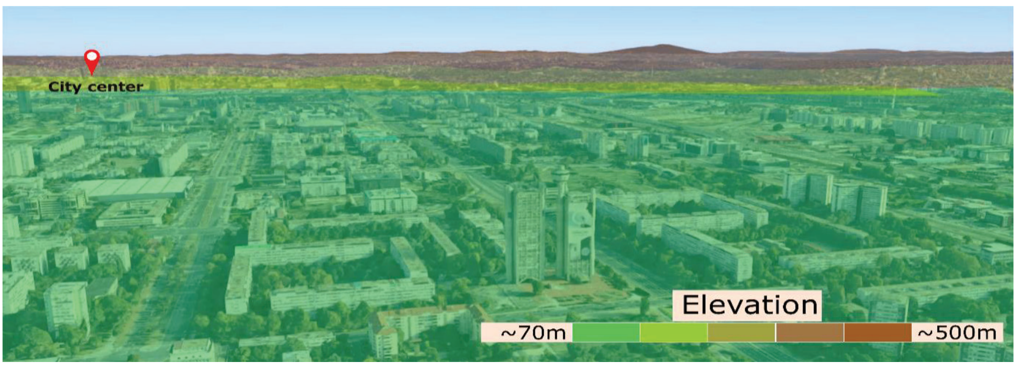

Figure 4. Relief of Belgrade

The city is divided into 17 municipalities. Most of them are located on the southern side of the Danube and Sava rivers. Three municipalities (Zemun, Novi Beograd, and Surčin), are on the northern bank of the Sava. A recent report (Popović, 2020) classifies the air quality in Belgrade as a level III category - excessively polluted air; therefore, certain improvements in the field of transport would be very welcome.

The general formulation of the considered problem of LMD mode selection is presented in Figure 5.

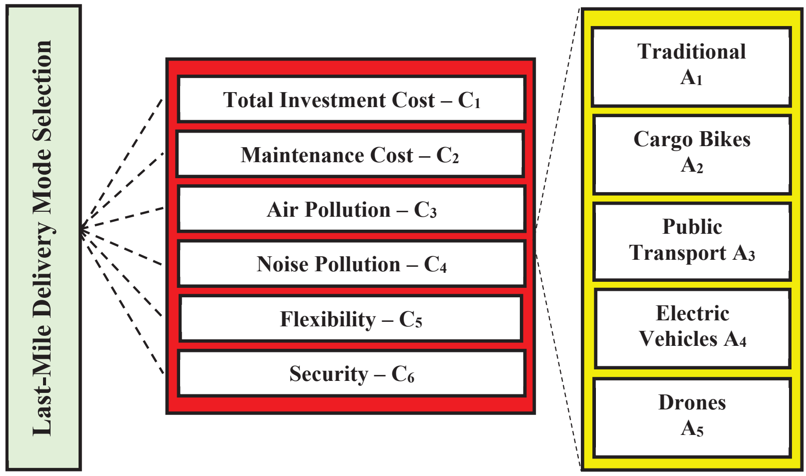

Figure 5. Formulation of the Last-Mile Delivery Problem

In this study, six criteria are taken to determine the best last-mile delivery (LMD) mode. The criteria that are used in this paper belong to the Economic (total investment cost and maintenance cost), Environmental (air pollution and noise pollution), and Technical (flexibility and security) pillars. The criteria are drawn from the previous research on LMD mode selection problem (Ferrer et al., 2018; Švadlenka et al., 2020). The description of each criterion is presented below:

Total Investment Cost (C_1) – the total cost that is necessary to launch the exact last-mile delivery mode. This type of criterion should be minimized. The total investment cost is expressed in Euros, per unit (per car, per drone, etc.)

Maintenance Cost (C_2) – the total cost that is necessary to maintain a possible last-mile delivery mode. This criterion also involves the cost of exploitation, and it's a type of criterion that also should be minimized.

Air Pollution (C_3) – the level of air pollution that should be affected by the determined last-mile delivery mode**.** This criterion is expressed on a scale from 1 to 10, where 1 means worst, while 10 means best air pollution.

Noise Pollution (C_4) – the level of noise that should be emitted by a particular last-mile delivery mode. This one is also expressed on a scale from 1 to 10, where 1 means low, while 10 means high pollution. This criterion should be minimized.

Flexibility (C_5) – the ability of a particular last-mile delivery mode to adapt to possible changes and contingencies. This criterion is expressed on a scale from 1 to 10, where 1 means a low level of flexibility, while 10 means a high level of flexibility. This criterion should be a max type.

Security (C_6) – the level of the last-mile delivery mode protection in terms of shipments security. This criterion is expressed on a scale from 1 to 10, where 1 means a low-security level, while 10 means a high-security level. This criterion should be a max type.

Five alternatives should be considered to find the best last-mile delivery mode solution.

Alternative 1 (A_1) – Traditional Last-Mile Delivery mode **-** This is the current LMD mode that is already being used in the territory of Belgrade.

Alternative 2 (A_2) – Cargo Bikes - Cargo Bikes are a relatively new solution for the LMD mode, and this mode should be suitable especially in urban areas since it is easier not only to ride into the city center but also to park, without any air pollution and noise emissions for the environment.

Alternative 3 (A_3) – Public Transport – The idea of including public transport as an LMD solution came from the experts the authors discussed regarding the topic. Public transport should be used as an LMD solution only to deliver items to inner-city hubs in the city since there are not any frequencies of travelers during the night hours.

Alternative 4 (A_4) – Electric Vehicles – This LMD solution is considered the possible one since there are no emissions on a large scale, air and noise pollution are minimized and the effect should be positive according to experts.

Alternative 5 (A_5) – Drones – This alternative is also considered as a possible LMD solution.

To evaluate the alternatives according to the established criteria, the expert's opinions are included in a decision-making process. The initial decision-making matrix is fulfilled by the experts. The information about experts is given in Table 1.

Table 1. The information about the experts

Expert	*Gender*	*Qualifications*	*Experience*
Expert 1	*Female*	*Ph.D.*	*Associate professor at the Postal Traffic Department with 15 years of experience*
Expert 2	*Male*	*Ph.D.*	*Associate professor at the Postal Traffic Department with 16 years of experience*
Expert 3	*Male*	*Ph.D.*	*Full professor at the Postal and Logistics Department with 19 years of experience*

The initial decision-making matrix is formulated and presented in Table 2.

Table 2. Initial decision-making matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0	1500	10	9	0	5
A_2	900	60	0	2	9	10
A_3	0	500	8	8	7	4
A_4	33000	50	0	8	9	10
A_5	3000	110	0	9	3	2

The normalization of the input data is given in Table 3. The obtained Weighted Sequences *Si* and *Pi* for each alternative, the total utility strategies and the final rank are presented respectively in Table 4, Table 5, and Figure 6.

When the CoCoSo method is applied, the following rank is obtained: the highest preference is assigned to Cargo Bikes (0.9529), followed by Public Transport (0.7903), Electric Vehicles (0.7247), Drones (0.6127), and Traditional one (0.3131), respectively.

Table 3. Normalization of the Input Data

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	1.0000	0.0000	0.0000	0.0000	0.0000	0.3750
A_2	0.9727	0.9931	1.0000	1.0000	1.0000	1.0000
A_3	1.0000	0.6897	0.2000	0.1429	0.7778	0.2500
A_4	0.0000	1.0000	1.0000	0.1429	1.0000	1.0000
A_5	0.9091	0.9586	1.0000	0.0000	0.3333	0.0000
Weights	0.3500	0.1700	0.1000	0.0900	0.0400	0.2500

Table 4. Obtained Weighted Sequences Si and Pi for each alternative

	C_1	C_2	C_3	C_4	C_5	C_6	Si	Pi	SiPi
A_1	0.3500	0.0000	0.0000	0.0000	0.0000	0.0938	0.4438	1.7825	2.2263
A_2	0.3405	0.1688	0.1000	0.0900	0.0400	0.2500	0.9893	5.9892	6.9785
A_3	0.3500	0.1172	0.0200	0.0129	0.0311	0.0625	0.5937	5.3266	5.9203
A_4	0.0000	0.1700	0.1000	0.0129	0.0400	0.2500	0.5729	4.8393	5.4122
A_5	0.3182	0.1630	0.1000	0.0000	0.0133	0.0000	0.5945	3.9170	4.5115
						min	0.4438	1.7825	25.0488
						max	0.9893	5.9892	

Table 5. Total Utility Strategies for each alternative and final rank

Kia	Kib	Kic	Rank	Kib norm
0.0889	2.0000	0.3190	0.3131	0.1028
0.2786	5.5893	1.0000	0.9529	0.2872
0.2364	4.3261	0.8484	0.7903	0.2223
0.2161	4.0058	0.7756	0.7247	0.2059
0.1801	3.5371	0.6465	0.6127	0.1818

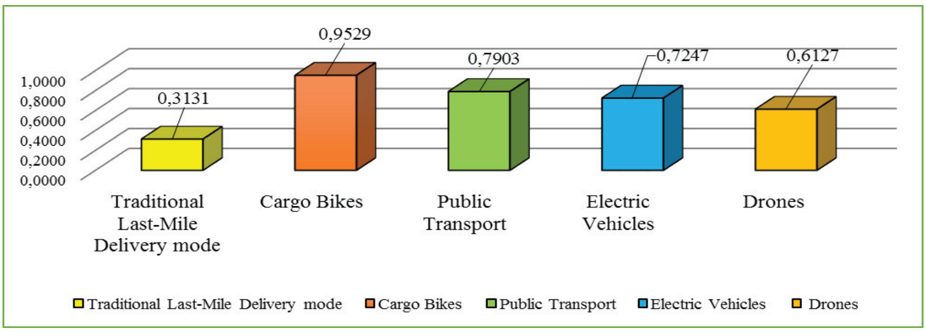

Figure 6. Final Ranking Alternatives

5. MANAGERIAL IMPLICATIONS

In city logistics, the last-mile delivery should be one of the most essential factors to achieve a high level of customer satisfaction. The quality of the last-mile delivery in cities depends on the appropriate LMD mode. In this regard, the municipalities should carefully monitor and assess the best last-mile delivery solutions, having this business more effective and sustainable in this way. Since there are numerous new LMD solutions in the market, it is essential to apply the best one. Without using some of the multi-criteria decision-making techniques, the problem of last-mile delivery mode selection can be considered harder and more uncertain to solve. It may badly affect not only the postal companies but also the final customers who are the most essential part of the last-mile delivery chain. This paper presented a possible approach for ranking the LMD solutions, and the results indicate the cargo bikes as the best solution for the Belgrade case.

6. CONCLUSION

This paper solved the LMD mode selection in Belgrade by applying the CoCoSo method. The five alternatives as possible solutions were considered and were compared according to six evaluation criteria. The results of the CoCoSo method indicate that the Cargo bikes are identified as the best possible alternative for Belgrade with a preference of 0.9529, followed by Public Transport (0.7903), Electric Vehicles (0.7247), Drones (0.6127), and Traditional mode (0.3131), respectively.

Cargo Bikes are becoming more and more popular in the city logistics field and have the potential for the future development of the postal traffic (Ali et al., 2022). The Bikes are flexible, without emissions, and can serve the city centers of urban areas more easily (Švadlenka et al., 2020). Public transport and electric vehicles should be considered in the future as a good choice for the LMD in urban areas, therefore special attention should be placed on those modes (Lazarević and Dobrodolac, 2020). When it comes to drones operating in Belgrade, there is still space to prepare the infrastructure and policies on a national level to be adopted to this model, according to experts' opinions. As a direction for future research, a more comprehensive methodological approach can be applied providing more insightful managerial implications.

REFERENCES

[1] Ali, S.S., Kaur, R., Khan, S. (2022). Evaluating sustainability initiatives in warehouse for measuring sustainability performance: an emerging economy perspective. Annals of Operations Research, 1-40.

[2] Biswas, T.K., Stević, Ž., Chatterjee, P., Yazdani, M. (2019). An integrated methodology for evaluation of electric vehicles under sustainable automotive environment, in: Chatterjee, P., Yazdani, M., Chakraborty, S., Panchal, D., Bhattacharyya, S. (Eds.), Advanced multi-criteria decision making for addressing complex sustainability issues, pp. 41-62. IGI Global.

[3] Dablanc, L. (2017). City Logistics. International Encyclopedia of Geography: People, the Earth, Environment and Technology, 1–8.

[4] Ecer, F., Pamucar, D. (2020). Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo'B) multi-criteria model. Journal of Cleaner Production, 266, 121981.

[5] Ferrer, J. M., Martín-Campo, F. J., Ortuño, M. T., Pedraza-Martínez, A. J., Tirado, G., & Vitoriano, B. (2018). Multi-criteria optimization for last mile distribution of disaster relief aid: Test cases and applications. European Journal of Operational Research, 269(2), 501-515.

[6] Hashemkhani Zolfani, S., Yazdani, M., Ebadi Torkayesh, A., & Derakhti, A. (2020). Application of a gray-based decision support framework for location selection of a temporary hospital during COVID-19 pandemic. Symmetry, 12(6), 886.

[7] Lazarević, D., Dobrodolac, M. (2020). Sustainability trends in the postal systems of last-mile delivery. Perner's Contacts, 15(1), 1-12.

[8] Mandal, S., Khan, D.A. (2022). Cloud-CoCoSo: Cloud Model-Based Combined Compromised Solution Model for Trusted Cloud Service Provider Selection. Arabian Journal for Science and Engineering.

[9] Peng, X., Smarandache, F. (2020). A Decision-making Framework for China's Rare Earth Industry Security Evaluation by Neutrosophic Soft CoCoSo Method. Journal of Intelligent & Fuzzy Systems, 39(5), 7571-7585.

[10] Popović, M. (2021). An MCDM approach for personnel selection using the CoCoSo method. Journal of Process Management and New Technologies. 9. 78-88.

[11] Popović, T. (2020). Report on air quality protection at the local self-government level in the Republic of Serbia. Available at: https://www1.undp.org/content/dam/serbia/Publications%20and%20reports/Aq%20report%20EN.pdf

[12] Ranieri, L., Digiesi, S., Silvestri, B., Roccotelli, M. (2018). A Review of Last Mile Logistics Innovations in an Externalities Cost Reduction Vision. Sustainability, 10(3):782

[13] Švadlenka, L., Simić, V., Dobrodolac, M., Lazarević, D., Todorović G. (2020). Picture Fuzzy Decision-Making Approach for Sustainable Last-Mile Delivery, IEEE Access, 8, 209393-209414.

[14] Turskis, Z., Bausys, R., Smarandache, F., Kazakeviciute-Januskeviciene, G., Zavadskas, E. K. (2022). M-generalised q-neutrosophic extension of CoCoSo method. International Journal of Computers Communications & Control, [S.l.], 17(1), 1-12.

[15] Ulutaş, A., Karakuş, C.B., Topal, A. (2020). Location Selection for Logistics Center with Fuzzy SWARA and CoCoSo Methods. Journal of Intelligent & Fuzzy Systems, 38(4), 4693-4709.

[16] UPU (2021). Postal economic outlook 2020 - Navigating accelerated change during an unprecedented crisis. Universal Postal Union, Berne, Switzerland

[17] WEF (2020). The future of the last-mile ecosystem: Transition roadmaps for public- and private-sector players, World Economic Forum, available at: http://www3.weforum.org/docs/WEF_Future_of_the_last_mile_ecosystem.

[18] Yazdani, M., and Chatterjee, P. (2018). Intelligent decision-making tools in manufacturing technology selection, in: Sidhu S., Bains P., Zitoune R., Yazdani M. (Eds.), Futuristic Composites. Materials horizons: from nature to nanomaterials, pp. 113-126. Springer, Singapore.

[19] Yazdani, M., Zarate, P., Kazimieras Zavadskas, E. and Turskis, Z. (2019). A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems. Management Decision, 57(9), 2501-2519.