SCIENTIFIC OASIS

Decision Making Advances

Journal homepage: www.dma-journal.org
ISSN: 2956-2384

An Extended AROMAN Method for Cargo Bike Delivery Concept Selection

Sara Bošković[1], Libor Švadlenka[1], Momčilo Dobrodolac[2], Stefan Jovčić[1,*], Marina Zanne[3]

[1] Faculty of Transport Engineering, University of Pardubice, Studentská 95, 53 210 Pardubice, Czech Republic
[2] University of Belgrade, Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11010 Belgrade, Serbia
[3] Faculty of Maritime Studies and Transport, University of Ljubljana, 6320 Portorose, Slovenia

ARTICLE INFO

Article history:
Received 14 April 2023
Received in revised form 9 May 2023
Accepted 23 May 2023
Available online 13 June 2023

Keywords: AROMAN; MCDM; Cargo Bikes; Last-Mile Delivery.

ABSTRACT

Nowadays, cargo bikes play a vital role in the last-mile delivery process. Parcel distribution by cargo bikes becomes a more accessible and ecologically friendly solution. This paper addresses the investment decision on the cargo bike delivery concept selection problem. We investigated a better solution in terms of whether the company needs to perform the delivery by investing in its fleet of cargo bikes or renting cargo bikes from a third party. The third solution is to combine those two alternatives. This case considers four criteria: cargo bike procurement cost, cargo bike maintenance cost, return on investment, and financial profitability. To solve this problem, we applied the extended alternative ranking order method accounting two-step normalization (AROMAN) method. The results compared with the MARCOS and ARAS methods confirmed that delivery concept 2 (i.e. renting cargo bikes from third-party providers) represented the best solution for the e-commerce company.

1. Introduction

The increase in online shopping, especially in urban areas, resulted in a rapid increase in the number of delivered parcels. Consequently, the number of delivery vehicles on the streets increased rapidly [1]. The necessity for sustainable development in urban areas calls for the adoption of more environmentally friendly delivery transport modes [2–3].

Cargo bikes becoming a very popular and sustainable solution when it comes to parcel distribution in urban areas [4]. A cargo bike is defined as a modified bicycle with a cargo box, enabling it to transport a variety of goods and loads [5]. One of the possible ways to achieve sustainable urban freight transport is by considering cargo bikes [6]. Parcel distribution by cargo bikes becomes an easier and ecologically friendly solution. With the minimal level of noise, zero-emission pollution, and a solid luggage capacity, postal and logistics companies are trying to move away from traditional delivery modes (gas and diesel-powered vehicles) to this more sustainable way [7]. Zhang *et al.* [8]

* *Corresponding author.*
E-mail address: stefan.jovcic@upce.cz

https://doi.org/10.31181/v120231

and Llorca & Moeckel [1] stated that replacing vans with cargo bikes could reduce costs and emissions derived from parcel delivery by 28 % and 22 %, respectively. Organizing a business process involves decision-making [9].

This paper considers an investment decision on cargo bike delivery concept selection using the extended Alternative Ranking Order Method Accounting Two-Step Normalization (AROMAN) multi-criteria decision-making (MCDM) approach. The authors of this paper investigated a better solution in terms of whether the company to perform the delivery by investing in its fleet of cargo bikes or renting cargo bikes from third-party. The third solution is the combination of the two types. Several essential criteria have been considered in this case: cargo bike procurement cost (C_1), cargo bike maintenance cost (C_2), return on investment (C_3), and financial profitability (C_4). For this research, three experts working for an e-commerce company in the Czech Republic participated in evaluating the alternatives. The names of the experts and company name are not mentioned due to their internal business policy. The top management of the company considers the possibility of investing in cargo bikes to perform parcel distribution to the final customers. On the other hand, there is also a possibility of renting cargo bikes from third parties.

The main motivation for this research appeared during the discussion with its top management where the authors offered the solution according to the expert's evaluation from the e-commerce company. To resolve this issue, the authors decided to apply the extended AROMAN approach. To compare the results, the MARCOS and ARAS methods were applied. The results of the comparative analysis indicate that the best solution for the e-commerce company is to rent cargo bikes from a third-party contractor.

The structure of the paper is organized as follows: Section 2 is the literature review. Section 3 is the description of the extended AROMAN method. Section 4 is the case study, while Section 5 gives the concluding remarks.

2. Literature Review

This section reviews the literature regarding cargo bikes as a sustainable last-mile delivery mode. The primary research sources were the Web of Science and Google Scholar databases. By reviewing the literature, it can be noticed that cargo bikes draw huge attention among scientists all around the world. Various issues regarding cargo bikes have been tackled.

For instance, Fikar *et al.* [10] proposed a decision support system to investigate dynamic last-mile distribution facilitating cargo bikes. Assmann *et al.* [11] provided an impact assessment model for the implementation of cargo bike transshipment points in urban districts. Büttgen *et al.* [12] evaluated the distribution costs and CO_2 emissions of a two-stage distribution system with cargo bikes in Innsbruck City. Dybdalen & Ryeng [5] addressed the issue of cargo bike insurance while operating on winter roads. Llorca & Moeckel [1] assessed the potential of cargo bikes and electrification for last-mile parcel delivery by simulating the urban freight flows. Naumov & Pawlus [13] addressed the optimal packing and routing problem to improve LMD using cargo bikes. Niels *et al.* [14] investigated the design and operation of an urban electric courier cargo bike system in Munich, Germany. Nürnberg [15] analyzed the usage of cargo bikes in urban logistics on the example of Stargard. Rudolph *et al.* [16] solved the localization of urban micro consolidation centers for LMD based on real demand data and city characteristics. Vasiutina *et al.* [17] considered the environmental impact of using cargo bikes in cities through a comprehensive review of the existing approaches. The research is summarized in Table 1.

Table 1
Review of the existing approaches in cargo bikes

Authors	Problem Addressed
Fikar *et al.* [10]	Dynamic last-mile distribution facilitating cargo-bikes
Assmann *et al.* [11]	Implementation of cargo bike transshipment points in urban districts
Büttgen *et al.* [12]	Distribution costs and CO_2 emissions of a two-stage distribution system with cargo bikes
Dybdalen & Ryeng [5]	Cargo bike insurance while operating on winter roads
Liorca & Moeckel [1]	The potential of cargo bikes and electrification for last-mile parcel delivery
Naumov & Pawlus [13]	Optimal packing and routing problem using cargo bikes
Niels *et al.* [14]	Design and operation of an urban electric courier cargo bike system
Nürnberg [15]	Usage of cargo bikes in urban logistics
Rudolph *et al.* [16]	Localization of urban micro consolidation centers for LMD
Vasiutina *et al.* [17]	Environmental impact of using cargo bikes in cities - review
Our Study	*Cargo Bike Delivery Concept Selection*

Based on the literature survey, the investment decision on cargo bike delivery concept selection has not been previously addressed. To fulfill the research gap, the authors of this paper address the investment decision on the cargo bike delivery concept selection issue.

3. An Extended AROMAN method

In this paper, an extended AROMAN method is applied. This method combines the normalized data from two-step normalization and obtains an average matrix from normalized data [18]. The extended AROMAN method can be described in the following steps:

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

Before the decision-making procedure starts, it is necessary to define the initial decision-making matrix with the input data. Depending on the problem, the input data are mostly gathered in advance, regarding the alternatives and criteria. Therefore, let us suppose we have a decision matrix X_{mxn} with the input data x_{11},..., x_{2j}, ... , x_{mn} as follows:

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

Step 2. Normalize the input data.

After the decision-making matrix with the input data is defined, the second step is to normalize the input data. This means that the input data should be structured in intervals between 0 and 1. There are two types of normalization, as defined in Eqs. (2)–(3).

Step 2.1 Normalization 1 (Linear):

$$t_{ij} = \left(x_{ij} - \min_i x_{ij}\right) / \left(\max_i x_{ij} - \min_i x_{ij}\right), \; i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n. \quad (2)$$

Step 2.2 Normalization 2 (Vector):

$$\boldsymbol{t_{ij}^{*}} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}}, \boldsymbol{i = 1, 2, \dots, m, j = 1, 2, \dots, n,} \tag{3}$$

where the normalization techniques in Step 2 are used for both criterion types (min and max).

Step 2.3 Aggregated averaged normalization.

The aggregated averaged normalization is done by applying the following equation:

$$\boldsymbol{t_{ij}^{norm}} = \frac{\beta t_{ij} + (1-\beta) t_{ij}^{*}}{2}, \boldsymbol{i = 1, 2, \dots, m;\ j = 1, 2, \dots, n.} \tag{4}$$

where t_{ij}^{norm} denotes the aggregated averaged normalization and β is a weighting factor varying from 0 to 1. In our case, we considered β to be 0.5.

Step 3. Multiply the aggregated averaged normalized decision-making matrix with the criteria weights to obtain a weighted DM matrix:

$$\widehat{\boldsymbol{t_{ij}}} = \boldsymbol{W_{ij} \cdot t_{ij}^{norm}}, \boldsymbol{i = 1, 2, \dots, m;\ j = 1, 2, \dots, n.} \tag{5}$$

Step 4. Separately summarize the normalized weighted values of the criteria type min (L_i) and the normalized weighted values of the max type (A_i).

This can be calculated by applying Eqs. (6)–(7) as follows:

$$\boldsymbol{L_i = \sum_{j=1}^{n} \widehat{t_{ij}}^{(min)}}, \boldsymbol{i = 1, 2, \dots, m;\ j = 1, 2, \dots, n,} \tag{6}$$

$$\boldsymbol{A_i = \sum_{j=1}^{n} \widehat{t_{ij}}^{(max)}}, \boldsymbol{i = 1, 2, \dots, m;\ j = 1, 2, \dots, n.} \tag{7}$$

Step 5. Raise the obtained sum of L_i and A_i values to the degree of λ.

$$\boldsymbol{L_i^{\wedge} = L_i^{\lambda} = \left(\sum_{j=1}^{n} \widehat{t_{ij}}^{(min)}\right)^{\lambda}, i = 1, 2, \dots, m,} \tag{8}$$

$$\boldsymbol{A_i^{\wedge} = A_i^{1-\lambda} = \left(\sum_{j=1}^{n} \widehat{t_{ij}}^{(max)}\right)^{1-\lambda}, i = 1, 2, \dots, m,} \tag{9}$$

where λ represents the coefficient degree of the criterion type. Since we included both criterion types, we considered parameter λ to be 0.5. However, there is a possibility to make variations of the parameter λ when considering the criteria type. For example, if the decision-making problem has two criteria of type min and 1 criterion of type max, this means that the coefficient λ can be 2/3. This logic can be followed to obtain the preference among the considered alternatives as well.

Step 6. Calculate the difference between the values $A_i^{\wedge}$ and $L_i^{\wedge}$ and apply the final ranking:

$$\boldsymbol{R_i = e^{(A_i^{\wedge} - L_i^{\wedge})}, i = 1, 2, \dots, m,} \tag{10}$$

where R_i denotes the final rank

4. Case Study

This section presents the case study where the extended AROMAN method found its application. The extended AROMAN method is applied to the cargo bike delivery concept selection. In other words, the authors of this paper investigated a better solution in terms of whether the company to perform the delivery by investing in its own fleet of cargo bikes or renting cargo bikes from third-party. The third solution is to combine those two alternatives. Four criteria have been considered in this case: cargo bike procurement cost (C_1), cargo bike maintenance cost (C_2), return on investment (C_3), and financial profitability (C_4). Besides, three experts participated in the alternative assessment procedure. All the experts belong to the e-commerce company in the Czech Republic. The alternatives are compared to the established criteria and assessed on a one-to-five-point scale. The criteria weights are also determined by the experts. The illustration of the problem is presented in Figure 1.

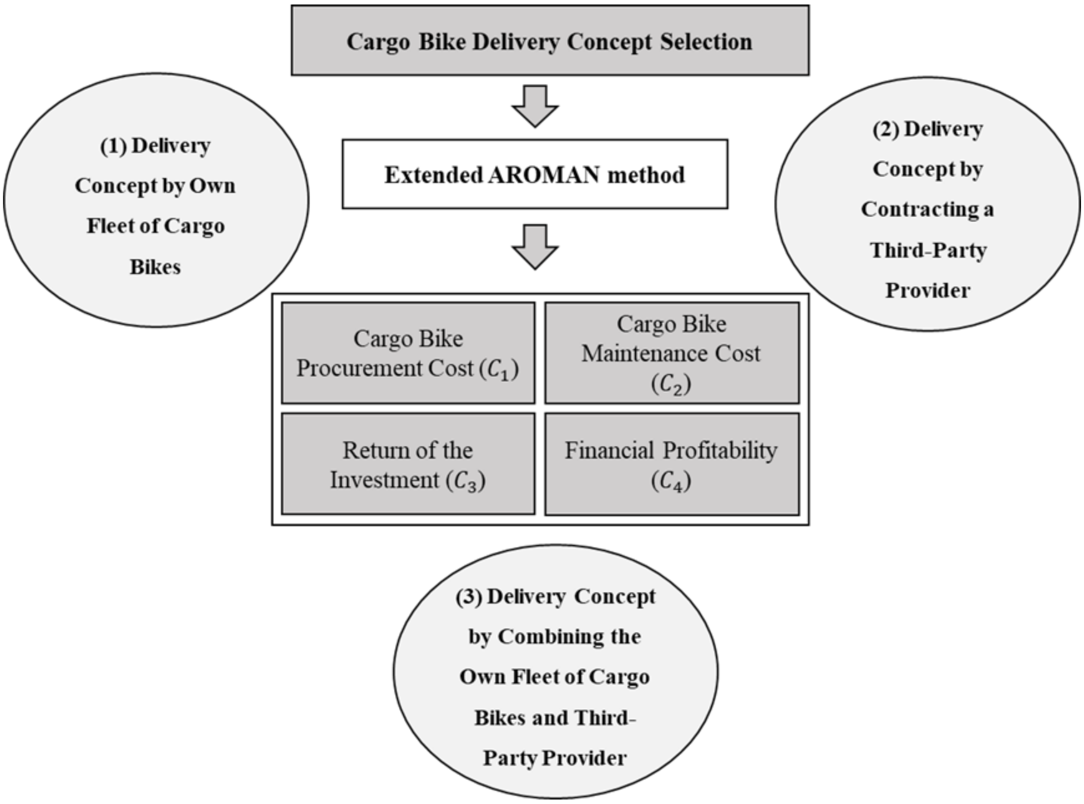

Fig. 1. Illustration of the problem

The assessment of each expert is presented in Tables 2-4.

Table 2
Expert's assessment of the first alternative

(1) Delivery concept by own fleet of cargo bikes	E_1	E_2	E_3	Overall Assessment
Cargo bike procurement cost	**5**	**5**	**5**	**5.0**
Cargo bike maintenance cost	**5**	**4**	**4**	**4.3333**
Return on the investment	**4**	**5**	**5**	**4.6667**
Financial profitability	**3**	**5**	**4**	**4.0**

Table 3
Expert's assessment of the second alternative

(2) Delivery concept by contracting a third-party provider	*E₁*	*E₂*	*E₃*	Overall assessment
Cargo bike procurement cost	2	1	1	1.3333
Cargo bike maintenance cost	2	2	1	1.6667
Return on the investment	1	1	2	1.3333
Financial profitability	4	5	4	4.3333

Table 4
Expert's assessment of the third alternative

(3) Delivery concept by combining the own fleet of cargo bikes and third-party provider	E_1	E_2	E_3	Overall assessment
Cargo bike procurement cost	2	1	1	1.3333
Cargo bike maintenance cost	2	2	1	1.6667
Return on the investment	1	1	2	1.3333
Financial profitability	4	5	4	4.3333

Based on the expert assessment, the input-data matrix is formulated and presented in Table 5.

Table 5
An initial decision-making matrix

	C_1	C_2	C_3	C_4
Delivery concept (1)	5	4.3333	4.6667	4
Delivery concept (2)	1.3333	1.6667	1.3333	4.3333
Delivery concept (3)	4.3333	3	4.667	5

The linear and vector normalizations are calculated and presented in Tables 6 and 7, respectively.

Table 6
Linear normalization of the initial decision-making matrix

	C_1	C_2	C_3	C_4
Delivery concept (1)	1.0	1.0	0.9999	0.0
Delivery concept (2)	0.0	0.0	0.0	0.3333
Delivery concept (3)	0.8182	0.5000	1.0	1.0

Table 7
Vector normalization of the initial decision-making matrix

	C_1	C_2	C_3	C_4
Delivery concept (1)	0.7408	0.7839	0.6931	0.5174
Delivery concept (2)	0.1975	0.3015	0.1980	0.5605
Delivery concept (3)	0.6420	0.5427	0.6931	0.6467

Table 8
Aggregated averaged normalization (β=0.5)

	C_1	C_2	C_3	C_4
Delivery concept (1)	0.4352	0.4460	0.4232	0.1293
Delivery concept (2)	0.0494	0.0754	0.0495	0.2234
Delivery concept (3)	0.3650	0.2607	0.4233	0.4117
Weights	0.28	0.26	0.22	0.24
min/max	*min*	*min*	*min*	*max*

Table 9
Aggregated averaged weighted normalized matrix with summarized criterion types

	Cargo bike procurement cost (C_1)	Cargo bike maintenance cost (C_2)	Return on the Investment (C_3)	Financial profitability (C_4)	L_i	A_i
Delivery concept 1	0.1219	0.1160	0.0931	0.0310	0.3309	0.0310
Delivery concept 2	0.0138	0.0196	0.0109	0.0536	0.0443	0.0536
Delivery concept 3	0.1022	0.0678	0.0931	0.0988	0.2631	0.0988
min/max	*min*	*min*	*min*	*max*		

Since λ is considered as 0.5, $L_i^{\wedge}$ and $A_i^{\wedge}$ values are calculated by applying Eq. (8) and Eq. (9), respectively. The final rank is calculated by applying Eq. (10) and the results are presented in Table 10.

Table 10
$L_i^{\wedge}$ and $A_i^{\wedge}$ values, its divergence, and final rank

$L_i^{\wedge}$	$A_i^{\wedge}$	$A_i^{\wedge} - L_i^{\wedge}$	Rank
0.5752	0.1761	-0.3991	0.6709
0.2105	0.2316	0.0210	1.0213
0.5129	0.3143	-0.1986	0.8199

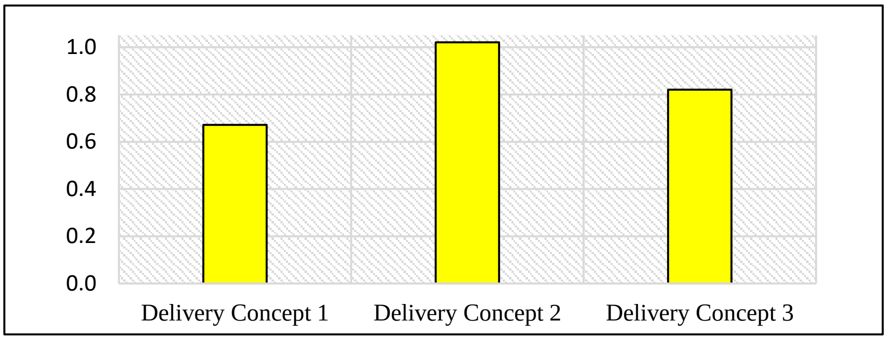

Fig. 2. Final ranking of the cargo bike delivery concepts

To compare the results obtained by the extended AROMAN method, MARCOS [19] and ARAS [20] are applied to the same case. The results of the comparative analysis are depicted in Figure 3.

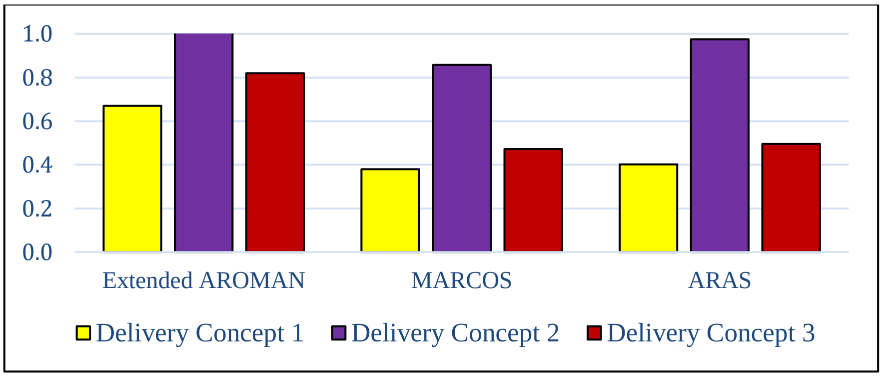

Fig. 3. Comparative Analysis

The results of the comparative analysis reveal that delivery concept 2 is the highest-ranked alternative in both cases. Therefore, it is strongly suggested to the e-commerce company to apply the cargo bike distribution concept 2 (i.e., to contact a third party and rent the fleet of cargo bikes to perform the delivery).

5. Conclusion

This paper addressed the investment decision on the cargo bike delivery concept selection problem in the e-commerce company. The extended AROMAN method was applied to the problem to rank the cargo bike delivery concepts. Three alternatives were considered: the delivery concept by using the own fleet of cargo bikes, the delivery concept by contracting a third-party provider, and the delivery concept by using a combination of the first two alternatives. The extended method ranked alternative 2 (the delivery concept by contracting a third-party provider) as the best solution for the e-commerce company. The second-best alternative was alternative 3, while the worst-ranked alternative was alternative 1 (the delivery concept by using the own fleet of cargo bikes). The obtained results are in line with other state-of-the-art research studies that investigate sustainable delivery modes [21–23].

To compare the results, the MARCOS and ARAS methods were applied, and the results show the same ranking order as the extended AROMAN method. The solution presented in this paper is limited only to the typical example of the e-commerce company since its experts participated in the decision-making process and evaluated the alternatives according to the company's perspective. However, the extended AROMAN method is general and can be used in such cases by various companies considering the cargo bike investment decision or any other decision-making problem.

The future direction of this paper should be to apply some other MCDM methods to evaluate and select the best third-party company from whom the e-commerce company should rent the cargo bikes to perform the delivery.

Acknowledgment
This research was supported by SGS_2023_017.

Conflicts of Interest
The authors declare no conflicts of interest.

References

[1] Llorca, C., & Moeckel, R. (2021). Assesment of the potential of cargo bikes and electrification for last-mile parcel delivery by means of simulation of urban freight flows. *European Transport Research Review, 13*(1), 33. https://doi.org/10.1186/s125 44-021-00491-5.

[2] Lazarević, D., & Dobrodolac, M. (2020). Sustainability trends in the postal systems of last-mile delivery. *Perner's Contacts, 15*(1). https://doi.org/10.46585/pc.2020.1.1547.

[3] Papaioannou, E., Iliopoulou, C., & Kepaptsoglou, K. (2023). Last-Mile Logistics Network Design under E-Cargo Bikes. *Future Transportation, 3*(2), 403-416. https://doi.org/10.3390/futuretransp3020024.

[4] Švadlenka, L., Vimić, V., Dobrodolac, M., Lazarević, D. & Todorović, G. (2020). Picture Fuzzy Decision-Making Approach for Sustainable Last-Mile Delivery. *IEEE Access, 8*, 209393-209414. https://doi.org/10.1109/ACCESS.2020.3039010.

[5] Dybdalen, Å., & Ryeng, E. O. (2022). Understanding how to ensure efficient operation of cargo bikes on winter roads. *Research in Transportation Business & Management, 44*, 100652. https://doi.org/10.1016/j.rtbm.2021.100652.

[6] Tipagornwong, C., & Figliozzi, M. (2014). Analysis of Competitiveness of Freight Tricycle Delivery Services in Urban Areas. *Transportation Research Record: Journal of the Transportation Research Board, 2410*, 76-84. https://doi.org/10.3141/2410-09.

[7] Lazarević, D., Švadlenka, L., Radojičić, V., Dobrodolac, M. (2020a). New Express Delivery Service and Its Impact on CO2 Emissions. *Sustainability, 12*(2), 456. https://doi.org/10.3390/su12020456.

[8] Zhang, L., Matteis, T., Thaller, C., & Liedtke, G. (2018). Simulation-based assessment of cargo bicycle and pick-up point in urban parcel delivery. *Procedia Computer Science, 130*, 18-25. https://doi.org/10.1016/j.procs.2018.04.007.

[9] Lazarević, D., Dobrodolac, M., Švadlenka, L., & Stanivuković, B. (2020b). A model for business performance improvement: a case of the postal company. *Journal of Business Economics and Management, 21*(2), 564-592. https://doi.org/10.3846/jbem.2020.12193.

[10] Fikar, C., Hirsch, P., & Gronalt, M. (2018). A decision support system to investigate dynamic last-mile distribution facilitating cargo-bikes. *International Journal of Logistics Research and Applications, 21*(3), 300-317. https://doi.org/10.1080/13675567.2017.1395830.

[11] Assmann, T., Lang, S., Müller, F., & Schenk, M. (2020). Impact Assessment Model for the Implementation of Cargo Bike Transshipment Points in Urban Districts. *Sustainability, 12*(10), 4082. https://doi.org/10.3390/su12104082.

[12] Büttgen, A., Turan, B., & Hemmelmayr, V. (2021). Evaluating Distribution Costs and CO2-Emissions of a Two-Stage Distribution System with Cargo Bikes: A Case Study in the City of Innsbruck. *Sustainability*, 13(24), 13974. https://doi.org/10.3390/su132413974.

[13] Naumov, V., & Pawluś, M. (2021). Identifying the Optimal Packing and Routing to Improve Last-Mile Delivery Using Cargo Bicycles. *Energies, 14*(14), 4132. https://doi.org/10.3390/en14144132.

[14] Niels, T., Hof, M. T., & Bogenberger, K. (2018). Design and operation of an urban electric courier cargo bike system. In: *2018 21st International Conference on Intelligent Transportation Systems (ITCS)* (pp. 2531–2537). IEEE. https://doi.org/10.1109/ITSC.2018.8569606.

[15] Nürnberg, M. (2019). Analysis of using cargo bikes in urban logistics on the example of Stargard. *Transportation Research Procedia, 39*, 360-369. https://doi.org/10.1016/j.trpro.2019.06.038.

[16] Rudolph, C., Nsamzinshuti, A., Bonsu, S., Ndiaye, A. B., & Rigo, N. (2022). Localization of relevant urban micro-consolidation centers for last-mile cargo bike delivery based on real demand data and city characteristics. *Transportation Research Record, 2676*(1), 365-375. https://doi.org/10.1177/03611981211036351.

[17] Vasiutina, H., Szarata, A., & Rybicki, S. (2021). Evaluating the environmental impact of using cargo bikes in cities: A comprehensive review of existing approaches. *Energies, 14*(20), 6462. https://doi.org/10.3390/en14206462.

[18] Bošković, S., Švadlenka, L., Jovčić, S., Dobrodolac, M., Simić, V., & Bačanin, N. (2023). An Alternative Ranking Order Method Accounting for Two-Step Normalization (AROMAN)–A Case Study of the Electric Vehicle Selection Problem. *IEEE Access, 11*, 39496-39507. https://doi.org/10.1109/ACCESS.2023.3265818.

[19] Stević, Ž., Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). *Computers & Industrial Engineering, 140*, 106231. https://doi.org/10.1016/j.cie.2019.106231.

[20] Zavadskas, E. K., & Turskis, Z. (2010). A new additive ratio assessment (ARAS) method in multicriteria decision-making. *Technological and Economic Development of Economy*, *16*(2), 159-172. https://doi.org/10.3846/tede.2010.10.

[21] Jovčić, S., Simić, V., Průša, P., & Dobrodolac, M. (2020). Picture fuzzy ARAS method for freight distribution concept selection. *Symmetry, 12*, 1062. https://doi.org/10.3390/sym12071062.

[22] Simić, V., Lazarević, D., & Dobrodolac, M. (2021). Picture fuzzy WASPAS method for selecting last-mile delivery mode: A case study of Belgrade. *European Transport Research Review*, 13, 43. https://doi.org/10.1186/s12544-021-00501-6.

[23] Smrčka, J., & Hruška, R. (2022). Analýza Ekonomického Hodnocení Projektů V City Logistice. *Perner's Contacts, 17*(1). https://doi.org/10.46585/pc.2022.1.2361.