Research Article

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General Application of Multiple Criteria Decision Making Methods for Finding the Optimal Solution in City Logistics

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Abstract: The aim of this paper is to familiarize the reader with the general application of MCDM methods on a specific example of City Logistics in order to find the optimal solution for operation of the territory. In its introductory part, methods used for quantitative evaluation of variant solutions are briefly described, and then the so-called Forces Decision Matrix Method (FDMM) including the determination of criteria weights using pairwise comparison of variants according to individual criteria on the specific example is applied. In the final part of the paper, the advantages and disadvantages of using this method for more complex tasks with multiple variant solutions based on the results of the practical example are evaluated and the so-called Saaty's method based on the quantitative pairwise comparison to partially eliminate differences in the mutual evaluation of weights and criteria is mentioned.

Keywords: City Logistics, FDMM, multi-criteria analysis, criterion weight, variant solutions

1 Introduction

Deciding between several alternatives, where only one optimum is accepted as a result of the whole process, is one of the frequent tasks of City Logistics that we can encounter in practical life. To solve this problem, several methods are used in common practice, which work essentially on a similar principle - first, to assess multiple variant solutions of a given problem according to selected criteria, and then to determine the final ranking of these variants. However, these methods differ from each other in the way in which we determine the weights between the individual criteria and how we evaluate the degree to which the variant solutions fulfilled the selected criteria [1]. In the following part of this paper, an introduction to the literature research and methods of multi-criteria analysis (including the methods for determination of criteria weights) are briefly presented, followed by the FDMM method using a pairwise comparison to determine criteria weights on the example when selecting the suitable vehicle for operation of the territory.

2 Literature review in the context of multi-criteria analysis

According to [2–4], MCDM method is a technique that combines alternative's performance across numerous, contradicting, qualitative and/or quantitative criteria and results in a solution requiring a consensus. Knowledge garnered from many fields, including behavioral decision theory, computer technology, economics, information systems and mathematics is used. Since the 1960s, many MCDM techniques and approaches have been developed, proposed and implemented successfully in many application areas [2, 5, 6]. The objective of MCDM is not to suggest the best decision, but to aid decision makers in selecting shortlisted alternatives or a single alternative that fulfills their requirements and is in line with their preferences [2, 7–9] mentioned that at early stages, knowledge of MCDM methods and an appropriate understanding of the perspectives of DM themselves (players who are involved in decision process) are essential for efficient and effective DM. There are several MCDM methods available such as the analytical hierarchal process (AHP), the analytical network process (ANP), TOPSIS, data envelopment analysis (DEA) and fuzzy decision-making [2, 10]. MCDM has been one of the fastest growing problem areas in many disciplines [2, 11]. Over the past decade, many researchers have applied these methods in the field of traffic engineering and City Logistics in making decisions [12, 13]. All the methods are equally capable of making decisions under uncer-

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tainty, and each one has its own advantages [2]. A prerequisite for using multi-criteria analysis is a larger number of quantifiable criteria that we include into decision making [14, 15]. The usual output of multi-criteria analysis can be either the selection of the optimal variant from the set of assessed variants, but also the ordering of individual variants in descending (ascending) order according to given preferences [16]. A typical use of multi-criteria analysis might be, for example, a decision-making process on a bypass road across a city that takes into account construction costs, environmental impacts, length of the driving time and other criteria [17]. According to [17], the method consists of four consecutive steps: identification of alternatives and criteria, evaluation (quantification) of criteria, allocation of weights (normalization) and calculation of evaluation. The first step involves identifying your own alternatives (between which we decide) and the criteria (which we want to include into the analysis). In the second step, we must evaluate these criteria numerically. If the criterion is already a numerical variable (*e.g.* price, distance, time, etc.) its value can be used directly. However, it is always necessary to perform the transformation so that the better variant is evaluated by a higher (or lower, which is less common) number. For this purpose, the minus sign can be prefixed to the numerical variables (the criterion can have a negative value) or subtracted from the appropriately selected constant. However, in case of numerical and non-numerical variables, the more common is (according to their advantageousness) to order variants from the least advantageous to the most advantageous and their sequential numbering by natural numbers 1, 2, 3, etc. In the case some alternatives are equal, it is possible to give them the same rating - it is not necessary that the value in all rows of the table was different [17, 18].

2.1 Determination of criteria weights and calculation of variant solutions evaluation

The quantification of criteria is followed by the third step of multi-criteria analysis, namely the allocation of individual weights to criteria (the so-called normalization). These weights must be allocated in such a way that the product of the criteria and weight evaluation corresponds to the meaning that the given criterion has for us [17, 18]. The ranking method, the scoring method and the various pairwise comparison methods are most commonly used to determine the criteria weights [19]. The ranking method works on the principle of allocating points to individual criteria according to their significance and then calculating the criteria weights from the proportion of allocated points for a given criterion and the sum of all allocated points among the criteria. This method works with ordinal information about the order of objects. The scoring method is beside the ranking method based on the scale selection and allocation of points to individual criteria, but that works with cardinal information quantifying the difference between objects (*e.g.* Metfessel's allocation). The third group of methods used for determination of criteria weights represents the various pairwise comparison methods. Some methods from this group require always to determine order in each pair (*e.g.* Fuller's method), while others allow equality when comparison in pair and might use even cardinal type of information (*e.g.* Saaty's method) [20–22]. The last step of multi-criteria analysis is the calculation of variant solutions evaluation. For custom selection of variants exist also a number of different methods, some of which might be combined. In the next part of the paper, the so-called Forces Decision Matrix Method (FDMM) using the determination of criteria weights by the pairwise comparison method will be applied to our concrete example when selecting the suitable vehicle for operation of the territory in City Logistics.

3 Application of FDMM method on the specific assignment

When applying the FDMM method, the weights of the individual criteria and the actual variant solutions evaluation are determined by the already mentioned pairwise comparison method. By the comparison of two criteria (variants), more important criterion (variant) is denoted by „1“, less important by „0“. This is followed by the mentioned standardization so that the sum of all criteria weights resp. variant solutions evaluation was equal to 1. To the main advantages of the FDMM method includes its simplicity, quick application to the given task and also the elimination of subjectivity in determining the criteria weights. The major disadvantage is the large variation in determination of criteria weights and the criteria evaluation [23].

3.1 Criteria

The following four criteria have been chosen to select the suitable vehicle for operation of the territory in City Logistics and are sorted in descending order according to their importance (significance) from the point of view of the po-

Table 1: Criteria values according to variant solutions [24].

Criterion / Variant solutions	D1	D2	D3	D4	D5	D6	D7
K1 [CZK]	1 141 143,-	1 141 668,-	1 105 787,-	1 009 019,-	978 769,-	913 550,-	846 879,-
K2 [m^3]	15.5	14.0	15.1	15.0	15.2	14.2	16.0
K3 [kg]	1 218	1 225	1 045	1 365	1 408	1 219	740
K4 [l/100 km]	7.9	7.7	7.6	6.4	8.5	7.8	8.3

Table 2: Standardization of individual criteria weights [author].

Criterion (i = 1,2,3,4)	K1	K2	K3	K4	Σw_i	Weight v_i
K1	-	1	1	1	3	0.50
K2	0	-	1	1	2	0.33
K3	0	0	-	1	1	0.17
K4	0	0	0	-	0	0.00
Σ	-	-	-	-	6	1.00

tential buyer of the vehicle. For our example, the following criteria were used:

K1: New vehicle purchase price [CZK],
K2: Loading space capacity indicated by the manufacturer [m^3],
K3: Vehicle payload indicated by the manufacturer [kg],
K4: Average vehicle consumption indicated by the manufacturer [l/100 km].

K1 and K4 are the minimization criteria (in case of comparison of variant solutions the variant with lower value of the criterion will be more preferable), while K2 and K3 are the maximization criteria (in case of comparison of variant solutions the variant with higher value of the criterion will be more preferable).

3.2 Variant solutions

As a variant solutions, a total of 7 light commercial vehicles from various manufacturers suitable for servicing the area with the urban character of the development were selected for the model example. These are the following vehicles:

D1: Volkswagen Crafter 35,
D2: Mercedes-Benz Sprinter 316 CDI,
D3: Ford Transit EcoBlue 170k,
D4: Citroen Jumper Furgon,
D5: Peugeot Boxer FT Active 350,
D6: Renault Master dCi 130 L3H3,
D7: Iveco Daily.

The values of individual criteria (K1 - K4) for these vehicles (D1 - D7) are listed in the following Table 1.

3.3 Determination of criteria weights

As stated in chapter 3 of this paper, by pairwise comparison of two criteria to determine their weight, more important criterion has the value „1“ and less important criterion has the value „0". Normalized weights of the individual criteria (the so-called significance coefficients in [%]) are then determined by the simple relation of standardization according to [25–27] as:

$$w_i > 0 \rightarrow v_i = \frac{w_i}{\sum\limits_{i=1}^{n} w_i} \quad (1)$$

on condition that

$$0 < v_i < 1; \; i = 1, \ldots, n \quad (2)$$

$$\sum_{i=1}^{n} v_i = 1 \; (100 \; \%)$$

where w_i is the partial sum of the significance of the i-th criterion (non-standard weight) [-], v_i is the standard weight of the i-th criterion [%] and n is the number of criteria.

If we apply this procedure to our model example, the table of pairwised comparison criteria will have the following form [28].

Criterion K1 will have the weight v_1 = 0.50, criterion K2 will have the weight v_2 = 0.33, criterion K3 will have the weight v_3 = 0.17 and criterion K4 will have the weight v_4 = 0.00.

3.4 Pairwise comparison of variants according to individual criteria

Similarly to the pairwise comparison of individual criteria according to their significance, we will apply this proce-

Table 3: Standardization of variant solutions weights' according to criterion K1 [author].

Variant solutions ($j = 1,\ldots,7$)	D1	D2	D3	D4	D5	D6	D7	Σw_j	Weight v_j
D1	-	1	0	0	0	0	0	1	0.05
D2	0	-	0	0	0	0	0	0	0.00
D3	1	1	-	0	0	0	0	2	0.09
D4	1	1	1	-	0	0	0	3	0.14
D5	1	1	1	1	-	0	0	4	0.19
D6	1	1	1	1	1	-	0	5	0.24
D7	1	1	1	1	1	1	-	6	0.29
Σ	-	-	-	-	-	-	-	21	1.00

Table 4: Standardization of variant solutions weights' according to criterion K2 [author].

Variant solutions ($j = 1,\ldots,7$)	D1	D2	D3	D4	D5	D6	D7	Σw_j	Weight v_j
D1	-	1	1	1	1	1	0	5	0.24
D2	0	-	0	0	0	0	0	0	0.00
D3	0	1	-	1	0	1	0	3	0.14
D4	0	1	0	-	0	1	0	2	0.09
D5	0	1	1	1	-	1	0	4	0.19
D6	0	1	0	0	0	-	0	1	0.05
D7	1	1	1	1	1	1	-	6	0.29
Σ	-	-	-	-	-	-	-	21	1.00

Table 5: Standardization of variant solutions weights' according to criterion K3 [author].

Variant solutions ($j = 1,\ldots,7$)	D1	D2	D3	D4	D5	D6	D7	Σw_j	Weight v_j
D1	-	0	1	0	0	0	1	2	0.09
D2	1	-	1	0	0	1	1	4	0.19
D3	0	0	-	0	0	0	1	1	0.05
D4	1	1	1	-	0	1	1	5	0.24
D5	1	1	1	1	-	1	1	6	0.29
D6	1	0	1	0	0	-	1	3	0.14
D7	0	0	0	0	0	0	-	0	0.00
Σ	-	-	-	-	-	-	-	21	1.00

Table 6: Standardization of variant solutions weights' according to criterion K4 [author].

Variant solutions ($j = 1,\ldots,7$)	D1	D2	D3	D4	D5	D6	D7	Σw_j	Weight v_j
D1	-	0	0	0	1	0	1	2	0.09
D2	1	-	0	0	1	1	1	4	0.19
D3	1	1	-	0	1	1	1	5	0.24
D4	1	1	1	-	1	1	1	6	0.29
D5	0	0	0	0	-	0	0	0	0.00
D6	1	0	0	0	1	-	1	3	0.14
D7	0	0	0	0	1	0	-	1	0.05
Σ	-	-	-	-	-	-	-	21	1.00

Table 7: Final decision table FDMM [author].

Criterion K_i	Criterion weight [-]	Weights of variant solutions D_j [-]							
		D1	D2	D3	D4	D5	D6	D7	Sum of weights [-]
K1 – purchase price [CZK]	0.50	0.05	0.00	0.09	0.14	0.19	0.24	0.29	1.00
K2 – loading space [m^3]	0.33	0.24	0.00	0.14	0.09	0.19	0.05	0.29	1.00
K3 – vehicle payload [kg]	0.17	0.09	0.19	0.05	0.24	0.29	0.14	0.00	1.00
K4 – consumption [l/100 km]	0.00	0.09	0.19	0.24	0.29	0.00	0.14	0.05	1.00
Weighted sum of weights [-]		0.12	0.03	0.10	0.14	0.21	0.16	**0.24**	1.00
Order of variant solutions		5.	7.	6.	4.	2.	3.	**1.**	

dure stated in the equation (1) and (2) also in pairwise comparison of variant solutions according to individual criteria. Since we work with a total of 4 criteria (K1 - K4) in the model example, the output will be 4 tables (see Tables 3, 4, 5 and 6) with standardized weights of variant solutions.

Such standardized weights of variant solutions according to individual criteria K1 - K4 will together with the standardized weights of these criteria (subchapter 3.3) enter the final decision table FDMM, from which it will be possible to determine the optimal variant solution (vehicle).

4 Discussion (Decision table FDMM)

When applying the FDMM method, all the standardized weights of the individual criteria are first multiplied with the standardized weights of variant solutions and then added together to obtain a weighted sum for each variant solution [29, 30]. The optimal variant solution (vehicle) is the one that has the highest weighted sum value. The optimal solution and the following order of variant solutions for our specific task demonstrate the Table 7.

Based on the multi-criteria analysis it is clear that the variant solution D7 (Iveco Daily) will be the most suitable vehicle for operation of the territory. According to the analysis, this variant solution (see Figure 1) seems to be optimal mainly due to its low purchase price and the large volume of loading space capacity. Although the vehicle payload and the average vehicle consumption compared to other vehicles (variant solutions) are disadvantageous, due to the insignificance of these criteria this fact does not have an essential impact on the final decision of the customer whether to purchase this vehicle or not.

As the second best vehicle fulfilling the given criteria was placed the variant solution D5 (Peugeot Boxer FT Active 350, see in Figure 2).

Figure 1: Variant solution D7 – Iveco Daily [31].

Figure 2: Variant solution D5 – Peugeot Boxer [32].

On the third place in our model example ended the variant solution D6 (Renault Master dCi 130 L3H3, see in Figure 3).

As already mentioned, the main advantage of the FDMM method is its simplicity and quick application. However, on a concrete example, man can see that there are quite large differences in the mutual evaluation of weights

Figure 3: Variant solution D6 – Renault Master [33].

and criteria, which might quite fundamentally affect the final decision on the optimal solution. To partially eliminate and reduce these large differences, it is preferable to use the so-called Saaty's method based on the quantitative pairwise comparison, which (in addition to selecting the preferred criterion) allows to determine the size of this preference by using a point scale of odd numbers from 1 to 9. For a more sensitive expression of the preference size, it is also possible to use the intermediate stage from even numbers from 2 to 8. Compared to the pairwise comparison of criteria and variant solutions applied to the model example (where we only work with two preferences „0“ and „1“), we have available up to nine preferences that allow a more sensitive differentiation of weights and criteria. The disadvantage of this method is especially for tasks with multiple criteria its duration (time consuming) and confusion. Generally (not only in the field of City Logistics), there are many other criteria that have to be further considered while making decisions. It always depends on the expert who carries out the research, which criteria will be taken into account and how their weights will be set.

5 Conclusion

The aim of this paper was to present the general application of MCDM method on a specific example of City Logistics in order to find the optimal solution for operation of the territory. In its introductory part, the literature review and several methods used for quantitative evaluation of variant solutions were described, and then the so-called Forces Decision Matrix Method (FDMM) including the determination of criteria weights using pairwise comparison of variants according to individual criteria on the specific example was applied. In the discussion, the advantages and disadvantages of using this method for more complex tasks with multiple variant solutions based on the results of the practical example were evaluated and the so-called Saaty's method based on the quantitative pairwise comparison to partially eliminate differences in the mutual evaluation of weights and criteria was mentioned.

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References

[1] Stopka O, Sarkan B, Chovancova M, Kapustina L. Determination of the Appropriate Vehicle Operating in Particular Urban Traffic Conditions. COMMUNICATIONS – Scientific Letters of the University of Zilina. 2017; 19(2): 18-22.

[2] Khan SA, Chaabane A, Dweiri FT. Multi-Criteria Decision-Making Methods Application in Supply Chain Management: A Systematic Literature Review [internet]. Multi-Criteria Methods and Techniques Applied to Supply Chain Management: Valerio A. P. Salomon, IntechOpen; 2018. Available from: https://www.intechopen.com/books/multi-criteria-methods-and-techniques-applied-to-supply-chain-management/multi-criteria-decision-making-methods-application-in-supply-chain-management-a-systematic-literatur. DOI: 10.5772/intechopen.74067

[3] Seydel J. Data envelopment analysis for decision support. Industrial Management & Data Systems. 2006; 106(1): 81-95.

[4] Kolios A, Mytilinou V, Lozano-Minguez E, Salonitis K. A comparative study of multiplecriteria decision-making methods under stochastic inputs. Energies. 2016; 9(7).

[5] Dadda A, Ouhbi I. A decision support system for renewable energy plant projects. 20 Multi-Criteria Methods and Techniques Applied to Supply Chain Management. In: Fifth International Conference on Next Generation Networks and Services (NGNS); 2014.

[6] Mardani A, Jusoh A, Nor KMD, Khalifah Z, Zakwan N, Valipour A. Multiple criteria decision-making techniques and their applications – A review of the literature from 2000 to 2014. Economic Research Istraživanja. 2015; 28(1): 516-571.

[7] Brito TB, Silva RCdS, Pereira RC, Medina AC. Discrete event Simulation combined with multi-criteria decision analysis applied to steel plant logistics system planning. Simulation. 2010; 2126-2137.

[8] Belton V, Stewart T. Multiple Criteria Decision Analysis: An Integrated Approach. Kluwer Academic Publishers. 2002.

[9] Dooley A, Smeaton D, Sheath G, Ledgard S. Application of multiple criteria decision analysis in the New Zealand agricultural industry. Journal of Multi-Criteria Decision Analysis. 2009; 16: 39-53.

[10] Stopka O, Stopkova M, Kampf R. Application of the Operational Research Method to Determine the Optimum Transport Collection

Cycle of Municipal Waste in a Predesignated Urban Area. Sustainability. 2019; 11(8). Article no: 2275. DOI: 10.3390/su11082275

[11] Triantaphyllou E. Multi-Criteria Decision Making Methods: A Comparative Study. Boston, USA: Springer. 2013.

[12] Lizbetinova L, Kampf R, Lizbetin J. Requirements of a Transport System User. COMMUNICATIONS – Scientific Letters of the University of Zilina. 2012; 14(4): 106-108.

[13] Fedorko G, Rosova A, Molnar V. The Application of Computer Simulation in Solving Traffic Problems. The Urban Traffic Management in Slovakia, Theor. Empir. Res. Urban Management. 2014; 9: 5-17.

[14] Zacek V. Management decisions: Theory, examples, solutions. Prague: Czech Technical University in Prague. 2015. ISBN 978-80-01-05804-6

[15] Meszaros F, Markovits-Somogyi R, Bokor Z. Modelling and multicriteria optimization of road traffic flows considering social and economic aspects. Logi - Scientific Journal on Transport and Logistics. 2012; 3(1): 70-82.

[16] Fiala P, Jablonsky J, Manas M. Multi-criteria Decision Making. Prague: University of Economics, Prague. 1994. ISBN 80-7079-748-7

[17] In the right direction. Multi-criteria analysis [internet]. Available from: http://spravnym.smerem.cz/Tema/Multikriteri%C3%A1ln%C3%AD%20anal%C3%BDza

[18] Chovancova M, Klapita V. Draft set of criteria for the inventory level optimization. Logi - Scientific Journal on Transport and Logistics. 2016; 7(1): 27-36.

[19] Kubisova A. Operational Research [internet]. Available from: https://www.vspj.cz/ISBN/Skripta%20-%20V%C5%A0PJ/Opera%C4%8Dn%C3%AD%20v%C3%BDzkum%20-%20Kubi%C5%A1ov%C3%A1%20Andrea.pdf

[20] WIKIPEDIA The Free Encyclopedia. Multi-criteria analysis of variants [internet]. Available from: https://cs.wikipedia.org/wiki/V%C3%ADcekriteri%C3%A1ln%C3%AD_anal%C3%BDza_variant

[21] Lizbetin J, Cerna L, Ľoch M. Model Evaluation of Suppliers in Terms of Real Company for Selected Criteria. NASE MORE. 2015; 62: 147-152. DOI: 10.17818/NM/2015/SI11

[22] Kubasakova I, Ivankova K, Sulgan M. City Logistics and Its Solutions. Logi - Scientific Journal on Transport and Logistics. 2010; 1(1): 71-78.

[23] Jancova B. Selection and Evaluation of Daniferra Suppliers: bachelor thesis [internet]. Zlín: Tomas Bata University in Zlín, Faculty of Logistics and Crisis Management; 2010. Available from: https://digilib.k.utb.cz/bitstream/handle/10563/15943/jan%C4%8Dov%C3%A1_2011_bp.pdf?sequence=1

[24] Seznam.cz a. s., SAUTO.CZ [internet]. Available from: http://www.sauto.cz

[25] Honcu M. Managerial Decision Making [internet]. Available from: https://slideplayer.cz/slide/2467569/

[26] Popov PV, Miretskij IY. Methodology for Constructing the Region's Logistics Infrastructure. EKONOMIKA REGIONA – ECONOMY OF REGION. 2019; 15(2): 483-492. DOI: 10.17059/2019-2-13

[27] Amaral RR, Semanjski I, Gautama S, Aghezzaf EH. Urban Mobility and City Logistics – Trends and Case Study. PROMET-TRAFFIC & TRANSPORTATION. 2018; 30(5): 613-622.

[28] Mrazovic P, Eser E, Ferhatosmanoglu H, Larriba-Pey JL, Matskin M. Multi-vehicle Route Planning for Efficient Urban Freight Transport. In: 9th International Conference on Intelligent Systems (IS); 2018; 744-753.

[29] Volkhin YG. Location Models for Distribution Centres. UPRAVLENETS-THE MANAGER. 2018; 9(2): 54-60. DOI: 10.29141/2218-5003-2018-9-2-9

[30] Alho AR, Silva J, Sousa JP, Blanco E. Improving Mobility by Optimizing the Number, Location and Usage of Loading/Unloading Bays for Urban Freight Vehicles. TRANSPORTATION RESEARCH PART D – TRANSPORT AND ENVIRONMENT. 2018; 61(A): 3-18. DOI: 10.1016/j.trd.2017.05.014

[31] LeaseVan.co.uk. Iveco Daily Van Leases [internet]. Available from: https://www.leasevan.co.uk/van-leasing/iveco/daily-van/

[32] Bristol Street Motors. Peugeot Boxer [internet]. Available from: https://www.bristolstreet.co.uk/new-van-deals/peugeot/boxer/220469/peugeot-boxer-330-l1-diesel-2.0-bluehdi-h1-van-130ps/

[33] Autowereld.nl. Renault Master [internet]. Available from: https://www.autowereld.nl/renault/master/l3h3-t35-dci-130-eu6-fwd-hoogste-korting-27028494/details.html