ORIGINAL SCIENTIFIC PAPER OPEN ACCESS

Comparison of fuzzy MCDM approaches in the elevator selection problem

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ARTICLE INFO

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DOI: 10.5937/engtoday2400009M

UDC: 621(497.11) **ISSN:** 2812-9474

Article history: Received 5 May 2024; Revised 18 June 2024; Accepted 28 June 2024

ABSTRACT

Considering a part of the problem in the domain of vertical transport, and above all elevators, it is noticeable that there are a large number of technically feasible alternatives in most cases. The designer's task is to choose from a set of possible solutions that best match the technical and economic conditions defined by the project task. The design and appropriate MCDM technique determine the quality of the recommended decision, saving computational time without sacrificing quality in the final ranking of alternatives. The task is to choose solutions that best match the technical and economic conditions. Therefore, selecting an adequate elevator is a problem that requires the manipulation of a large number of different data and, at the same time, the inclusion of a significant number of relevant criteria and goals that can often conflict. Fuzzy logic has proven excellent in models where intuition and judgment are primary elements. This paper aims to present a systematic overview of the developed fuzzy MCDM techniques. By ranking and comparative analysis of the results, this research represents an attempt to choose a method to support decision-making and create a comprehensive tool in the elevator selection process.

KEYWORDS

Elevator, Criteria, MCDM, Fuzzy, AHP, TOPSIS, VIKOR, MODIPROM

1. INTRODUCTION

The realization of increasingly demanding urban planning requirements, primarily aimed at the construction of high-rise residential, business, and public buildings on the one hand, and the need for better use of construction land and communal infrastructure on the other hand, imposed the need for the development and improvement of vertical transport in every aspect. The elevator is a unique set of mechanical and electrical systems whose dynamic characteristics depend on the mechanical, structural, and electrical system parameters. The basis of the elevator design, production, and operation process is built on two fundamental principles: safety and reliability. These principles are non-negotiable and form the basis of any decision regarding elevator selection. The goal is to minimize installation costs without compromising safety and reliability, crucial factors in choosing the most suitable elevator solution. In addition, numerous other factors (technical specifications, quality, equipment reliability, maintenance aspects, energy efficiency, etc.) should also be considered when making the optimal choice.

In the realm of vertical transport, particularly elevators, many technically feasible alternatives exist in most scenarios. The designer navigates this complexity, selecting potential solutions that align with the project's technical and economic parameters. Choosing the most suitable elevator solution is a complex problem that requires manipulating diverse data and often involves conflicting criteria and goals.

This paper provides an overview of the developed MCDM techniques and their application in the field of elevators, the extension of methods using fuzzy logic, as well as the most common problems present during the stages of defining criteria and their relative weights, working with massive data (a large number of criteria and alternatives), as well as the final ranking procedure or selection of the most desirable alternative. This research represents efforts to enable the most efficient decision-making process and the possibility of solving a wide range of real engineering problems.

1.1. Related works

Vertical transport has developed rapidly and constantly and continues to develop along with the progress of technique and technology. Therefore, bearing in mind the fact that the elevator is an integral part of a construction object and must fully respond to its purpose, an adequate and correct vertical transport solution is of great importance, and it begins first by determining the required parameters (speed and capacity) and the number of elevators. Sustainability, i.e. energy consumption, adequate choice of materials, safety or life expectancy, are also indispensable trends in the construction of modern buildings that must be followed by elevators as an integral part of them.

The most common problems in standard MCDM techniques are defining criteria, determining their number and relative weight, and ranking alternatives. The apparent multidimensionality indicates many different approaches and models for formulating and solving these problems. The most frequently used approach is applying the analytical hierarchical process - AHP [1,2]. Numerous attempts to solve the problem of choosing elevators using multicriteria decision-making can be seen by reviewing the literature. A study on elevator selection using AHP was conducted in vertical transportation [3]. The authors highlighted four general criteria: quality, availability, price, and time. This research uses AHP to select the best elevator option by comparing commercial proposals/bids. Research by a group of authors [4] shows the managerial way of choosing an elevator. Twenty-five criteria were classified into two categories to give the user a clear and accurate picture of the elevator selection process. Sustainable design of elevators in public hospitals by applying multicriteria analysis and, above all, by defining criteria through three categories (social, economic and environmental) was shown in the research of a group of authors [5]. The analysis of the results was carried out using the TOPSIS method. With the development of technology, intelligent elevator control systems have also attracted the attention of researchers [6]. Numerous mathematical methods have been developed and focused on the problems of selecting elevator sensor systems in high-rise buildings [7], i.e. the problem of minimizing passenger waiting time [8], as well as forecasting traffic flows [9]. Tervonen T. et al. [10] formulates the elevator planning problem as a stochastically discrete multicriteria decision-making problem. The problem is analyzed using the Stochastic Multicriteria Acceptability Analysis (SMAA) method to identify the configuration that best meets the stakeholders' goals.

Traditional approaches to elevator risk assessment, such as fault tree analysis, have long been the norm. However, with the development of the elevator industry and the need for practical risk assessment in elevator operations, this paper proposes a new method based on fuzzy theory and machine learning. In vertical transportation, the integration of machine learning can improve the accuracy of elevator operation risk assessment by analyzing collected data [11]. This method effectively overcomes the risk of converging to a local optimum, demonstrating superior accuracy and stability compared to other optimization algorithms. The technique [12] comprehensively considers failure probability, search cost, location time cost, and location correlation. In contrast to traditional fault tree analysis, the problem-solving sequence obtained by this method is more objective and reasonable, and the process of fault diagnosis and localization is faster and more efficient, highlighting the superiority of our approach. In recent years, problems related to group decision-making, the subjectivity of decision-makers and the use of qualitative expressions for alternative values by individual criteria have been demonstrated by numerous extended methods based on generalized fuzzy numbers, e.g. in the case of material handling equipment selection [13, 14, 15] or equipment characteristics [16, 17, 18]. By combining methods for determining the relative importance of criteria and procedures for ranking alternatives, an optimal decision is made on some multicriteria issues, regardless of the nature of the parameters that describe it. In addition, applying a combination of classical MCDM techniques with the theory of fuzzy logic and sets is also significant [19]. Fuzzy logic has proven excellent in models where intuition and judgment are primary elements.

This paper presents a developed approach for purpose of elevator selection, utilizing MCDM methods in conjunction with fuzzy logic. The authors have effectively used triangular fuzzy numbers to express the value of specific conflicting criteria, enabling a more informed and accurate decision-making process. The rest of the paper is organized as follows: Chapter 2 presents the research methodology, the basis of the fuzzy set’s theory, and the four fuzzy MCDM methods used in a case study. Chapter 3 provides a numerical example of elevator selection, with a comparative analysis of the final ranking of alternatives using different approaches and similarity measures. The last chapter of the research offers concluding remarks and directions for future research.

2. RESEARCH METHODOLOGY

2.1. Fuzzy set theory

Fuzzy logic arose due to attempts to model human thinking, experience and intuition in the decision-making process based on imprecise data. The application of fuzzy theory and sets was due to the frequent actions of decision-makers in conditions of uncertainty or the so-called 'partial truths'. Thanks to the exceptional usability of fuzzy logic in treating uncertainty and indeterminacy, the use of estimation models based on the theory of fuzzy sets and numbers can provide an acceptable solution. The original creator of fuzzy logic, L. A. Zadeh, made a groundbreaking contribution to the field of fuzzy sets [20]. His work laid the foundation for the development of fuzzy logic and its applications in various fields.

To consider the problem of choice as close as possible to human thinking, the evaluations of the proposed alternatives about the defined criteria given by the expert team members can be in linguistic form and not only in numerical form. Therefore, we must not forget that in some cases, the values that specific alternatives take according to certain criteria during multi-criteria analysis are not given quantitatively but also through appropriate linguistic expressions. For instance, in a decision-making scenario where the criteria are ″cost ″, ″quality ″, and ″time″, the expert team might express their evaluations as "high cost ", "'medium quality", and "low time". A large number of conversion scales are provided for converting linguistic expressions into a fuzzy number in the literature [21]. Which scale will be used depends on the number of linguistic statements converted into fuzzy numbers. The classification of fuzzy MCDM methods is shown in Fig. 1.

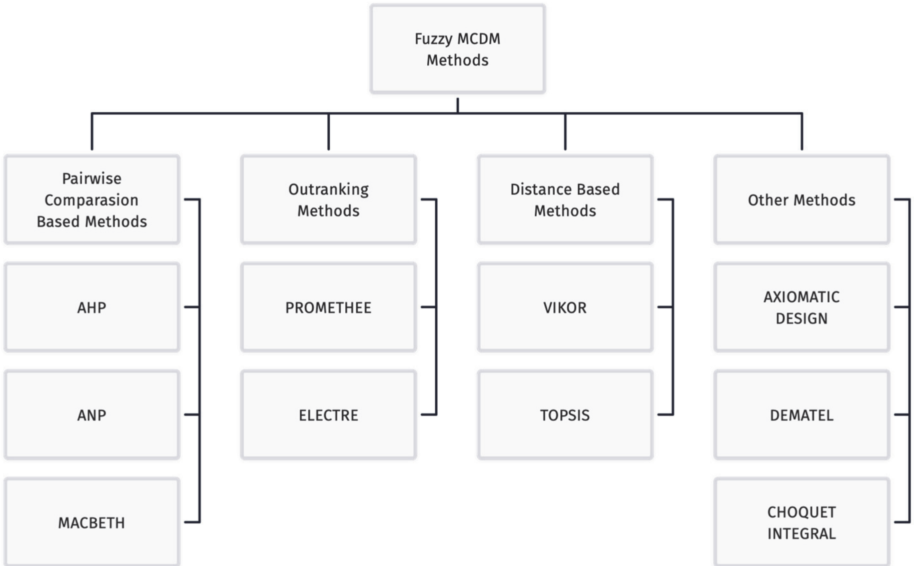

Figure 1: Classification of Fuzzy MCDM methods

A fuzzy number A of the set X is a triangular number if its membership function is $x \in \tilde{A}, \mu_{\tilde{A}}(x): X \to [0,1]$ and it can be described by the equation:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), l \le x \le m \\ (u-x)/(u-m), m \le x \le u \\ 0, \quad \text{остало} \end{cases} \tag{1}$$

A triangular fuzzy number taking three values: *l* - the left limit of the fuzzy number, *u* – mean value of the fuzzy number and *m* - the right limit of the fuzzy number. Arithmetic operations with two positive triangular fuzzy numbers can be performed according to the following expressions:

• addition of two fuzzy numbers:

$$(l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

• subtraction of two fuzzy numbers:

$$(l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \tag{3}$$

• multiplication of two fuzzy numbers:

$$(l_1, m_1, u_1) x (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \tag{4}$$

• Quotient of two fuzzy numbers:

$$(l_1, m_1, u_1) / (l_2, m_2, u_2) = (l_1 / u_2, m_1 / m_2, u_1 / l_2) \quad (5)$$

• Inverse number:

$$(l_1, m_1, u_1)^{-1} = (1/l_1, 1/m_1, 1/u_1) \quad (6)$$

• The product of a fuzzy number and any real number α:

$$\alpha x (l_1, m_1, u_1) = (\alpha l_1, \alpha m_1, \alpha u_1) \quad (7)$$

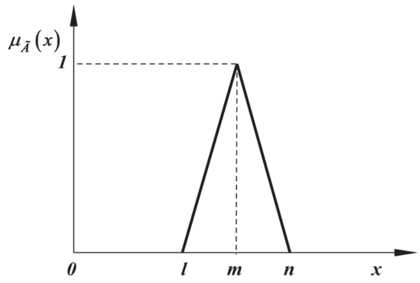

Figure 2: Membership function of triangular fuzzy number (TFN)

2.2. Fuzzy MODIPROM

The integrated approach F-MODIPROM (Fuzzy-MODified PROmethee Method) [21] is a combination and extension of some formulated models for ranking the alternatives, as well as for analyzing the sensitivity of the final order of alternatives due to the change of the relative weight criteria. The proposed algorithm of the integrated approach, with all the mentioned elements, is shown in Figure 3. The MODIPROM method, which is combined with the theory of fuzzy sets, is based on improving a group of methods for multi-criteria ranking: by changing existing generalized criteria and introducing new ones, the procedure of selecting generalized criteria within one criterion function, analysis of effects of change of weight coefficients, transformation of the mean values of the outranking flow for the purpose of solving complex criterion functions and the possibility of taking into account the linguistic expressions of the importance of criteria. The developed method for decision-making is carried out in several stages, for multiple criteria scenarios and with the possibility of taking into account the linguistic expressions of the importance of criteria.

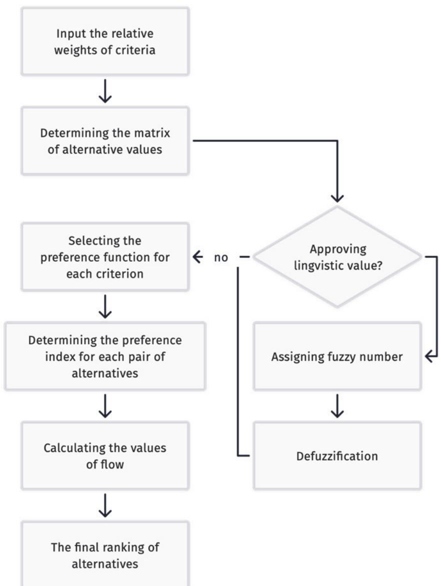

Figure 3: An integrated approach F-MODIPROM

2.3. Fuzzy AHP

Fuzzification of conventional AHP method was carried out by using triangular fuzzy numbers and interval arithmetic to determine the weights of criteria and alternatives, starting from the scale of the relative importance and evaluation in pairs including all necessary matrix operations. Triangular fuzzy numbers are used to improve the process of scaling in the formation of comparison matrix, while fuzzy arithmetic is used to determine the fuzzy vector eigenvalues.

The procedure of this approach [22] can be presented in several steps: the determination of criteria weights i.e. the relative strength of the two elements at the same level of hierarchy by using triangular fuzzy numbers, the formation of fuzzy comparison matrix, the determination a fuzzy eigenvalue and calculating the consistency index (CI) and consistency ratio (CR).

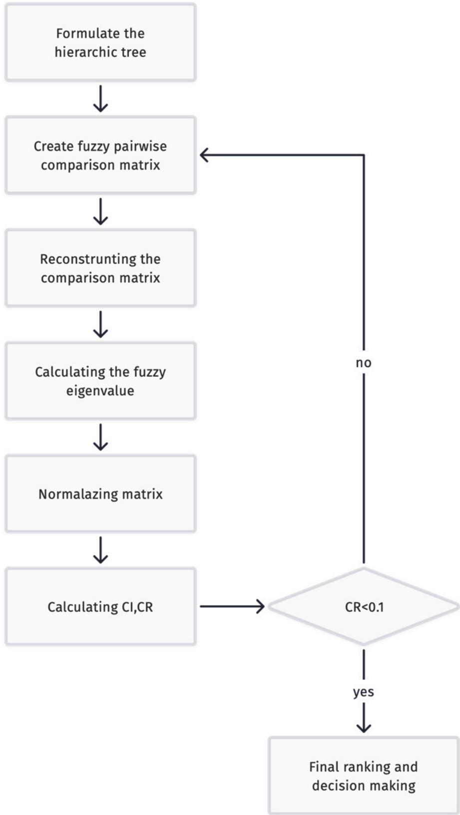

Figure 4: Fuzzy AHP flowchart

2.4. Fuzzy TOPSIS

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a technique created in 1981 by Hwang and Yoon [23]. Its main idea is to rank the alternatives based on the distance between the positive ideal and the negative ideal solutions. Chen proposed an extension of the TOPSIS method to interval type-2 fuzzy sets [24].

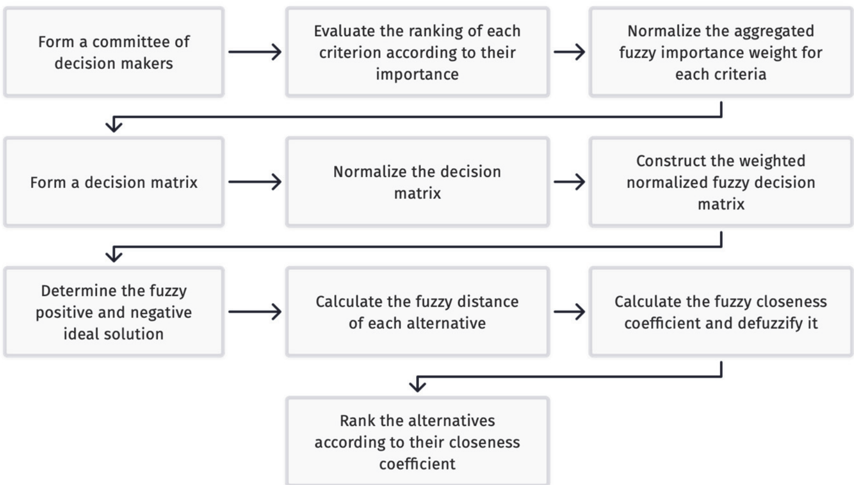

Figure 5: Fuzzy TOPSIS

2.5. Fuzzy VIKOR

The VIKOR (VIsekriterijumska Optimizacija I Kompromisno Resenje) technique is a method based on a compromise approach, where the compromise solution is closest to the ideal solution with some concessions. The VIKOR method has a fuzzy logic extension which was proposed in papers [25, 26].

The steps of the fuzzy VIKOR method are presented in Figure 6.

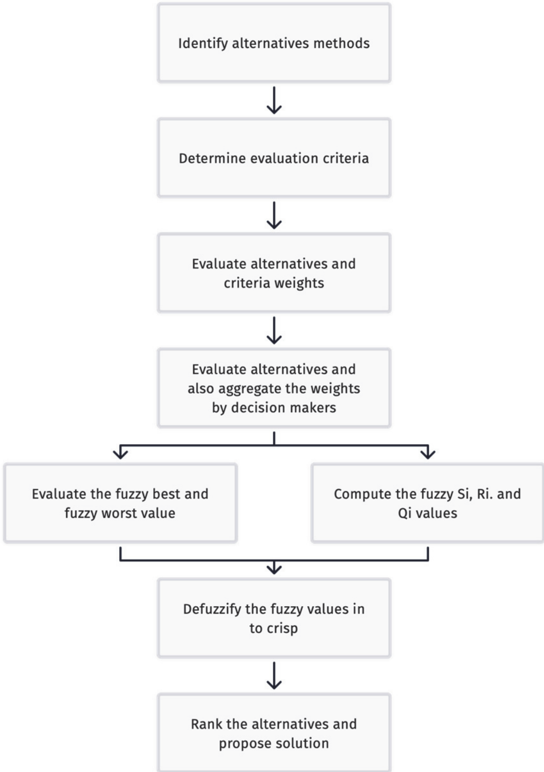

Figure 6: Fuzzy VIKOR flowchart

2.6. Similarity measures

The main objective of MCDM methods is usually to establish a ranking of alternatives, where the best solution is in the first place and the worst in the last place. However, using different techniques to solve the same decisional problem may result in rankings that are not the same. For purpose of testing a similarity, authors [27] are used the different correlation measures i.e. a new coefficient that is much better suited to compare the reference ranking and the tested rankings. This similarity rank coefficient WS is based on approach where the positions at the top of rankings have a significant similarity effect. The rank similarity coefficient can be presented by equation:

$$WS = 1 - \sum_{i=1}^{N} 2^{-x_i} \frac{|x_i - y_i|}{max(|x_i - 1|,|x_i - N|)} \tag{8}$$

where are: N is a length of ranking, x_i and y_i mean the place in the ranking for $i-th$ element in respectively ranking x and ranking y. The first part of equation (2^{-x_i}) is responsible for making the WS value dependent on the position in the reference ranking, and the second component determines to what extent the difference in rankings affects the similarity of rankings.

3. NUMERICAL EXAMPLE

The paper discusses the problem of decision-making when choosing the optimal elevator solution. The data was prepared based on the bids received for the parameters necessary for installing the elevator in the building. Several criteria were selected and classified into four groups of the max and min types, which correspond to costs and profit. The criteria, with name, type and units, are shown in Table 1. Five alternatives are selected, with the decision maker using their preferences given in the form of fuzzy triangular numbers due to their understanding and popularity in solving MCDM problems. For constant values of criteria were used singletons, because they must be constant.

Table 1: Criteria-subcriteria with types and units

Criteria	Label of criteria	Subcriteria with units	Type of subcriteria
Law/regulatory	K_1	K_{11} - Deadline for installation (months/days)	min
		K_{12} – Warranty period (months/days)	max
		K_{13} - Delivery deadline (months/days)	min

Criteria	Label of criteria	Subcriteria with units	Type of subcriteria
Social/	K_2	K_{21} – Level of noise (dB)	min
		K_{22} - max jerk (m/s^3)	min
		K_{23} – ergonomics and safety (fuzzy)	max
		K_{24} - indoor environmental quality (fuzzy)	max
		K_{25} - vertical vibration level 1-100 HZ (dB)	min
Economical	K_3	K_{31} – Purchase costs without construction works	min
		K_{32} – Energy consumption (kW/h)	min
		K_{33} – Maintenance-servicing costs (eur)	min
Technical	K_4	K_{41} – Power (kW)	max
		K_{42} – travel speed (m/s)	max
		K_{43} – travel time (s)	min

The alternatives, along with fuzzy numbers values for all alternatives are given in Table 2. After defining the alternatives' fuzzy value matrix, the other options were ranked using four fuzzy methods F-MODIPROM, Fuzzy TOPSIS, Fuzzy VIKOR and Fuzzy AHP.

Table 2: Key criteria for elevator selection

Label	Selected criteria for MCDM	Relative weights
K_1	K_{11} – Warranty period (month)	0.14285
K_2	K_{12} – Level of noise (dB)	0.14285
K_3	K_{13} – Max jerk (m/s^3)	0.14285
K_4	K_{21} – Ergonomics and safety (fuzzy)	0.14285
K_5	K_{22} - Purchase costs without construction works (eur)	0.14285
K_6	K_{23} – Energy consumption (kWh)	0.14285
K_7	K_{24} - Power of gearless machine (kW)	0.14285

The relative weights of the criteria are equal for each of the mentioned methods. When changing the Fuzzy VIKOR method, the parameter υ=0.5. The comparative ranking results obtained by the mentioned methods are shown in Table 4.

Table 3: Values of alternatives for each criterion

Criteria	TFN	Alternatives					ωj	max/min
		A1	A2	A3	A4	A5		
K_1	l	36	36	24	24	24	0.14285	min
	m	36	36	24	24	24		
	n	36	36	24	24	24		
K_2	l	50	48	50	49	51	0.14285	min
	m	50	48	50	49	51		
	n	50	48	50	49	51		
K_3	l	2	1.8	2.1	2	2	0.14285	min
	m	2	1.8	2.1	2	2		
	n	2	1.8	2.1	2	2		
K_4	l	16	12	8	16	16	0.14285	max
	m	20	15	11	20	20		
	n	20	18	14	20	20		
K_5	l	25000	27000	24000	28000	23000	0.14285	min
	m	25000	27000	24000	28000	23000		
	n	25000	27000	24000	28000	23000		
K_6	l	7184,43	8461,125	10140,597	10067,103	11166,66	0.14285	min
	m	7982,7	9401,25	11267,33	11185,67	12407,4		
	n	8780,97	10341,375	12394,063	12304,237	13648,14		
K_7	l	5,7	5,35	4,97	4,9	5,9	0.14285	min
	m	5,7	5,35	4,97	4,9	5,9		
	n	5,7	5,35	4,97	4,9	5,9		

Table 4: Comparations of ranking obtained using a four fuzzy MCDM methods

Alternatives	Results of ranking obtained using a four fuzzy MCDM methods			
	F-MODIPROM	Fuzzy TOPSIS	Fuzzy AHP	Fuzzy VIKOR
A1	2	2	2	2
A2	1	1	1	1
A3	4	5	4	5
A4	5	3	5	4
A5	3	4	3	3

Figure 7 shows the similarity of the results obtained by changing MCDM methods and the values obtained by calculating the WS coefficient. The most significant similarity was achieved between F-MODIPROM and Fuzzy AHP (1) or F-MODIPROM and Fuzzy VIKOR (0.971354). A considerable similarity was achieved between Fuzzy VIKOR and Fuzzy AHP (0.971354). The lowest correlation was achieved between Fuzzy TOPSIS and AHP (0.846).

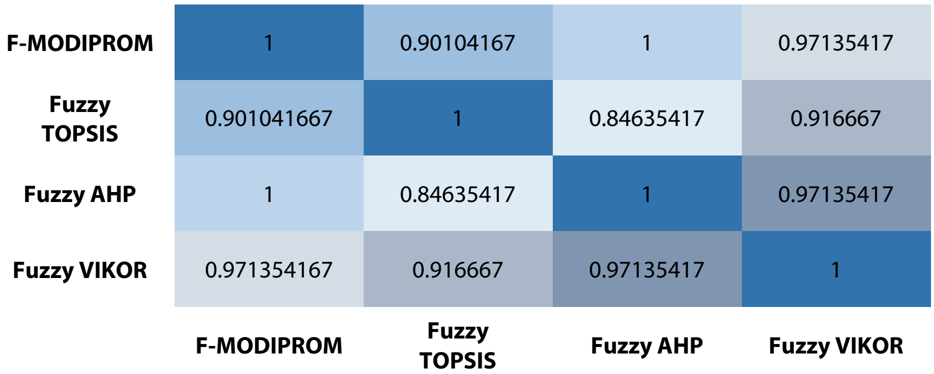

Figure 7: WS correlation maps for fuzzy MCDM methods

4. CONCLUSION

The conducted research not only provides a systematic overview of the developed fuzzy MCDM techniques and a description of the developed approach but also highlights their practical application in solving real-world problems of elevator selection. By ranking and comparative analysis of the results of 5 elevator alternatives obtained for given parameters and seven criteria from four groups, this research aims to assist decision maker (DM) in choosing an adequate MCDM method and support decision-making in a tangible way. Special attention is focused on the selection and definition of criteria in the domain of elevator facilities and their number, further enhancing the practical relevance of the findings. The proposed approach, a novel amalgamation and extension of existing models, holds a unique specificity. It introduces a function of preference, alters existing generalized criteria, and implements a new, automated procedure for selecting generalized criteria. The analysis also delves into the impact of changes in relative weights on the final order of alternatives, enriched by a comprehensive set of fuzzy theories. Therefore, the research not only indicates the need for a comparative analysis of the fuzzy MCDM approach and the selection of an adequate procedure in the procedure of choosing the optimal elevator solution, especially in conditions of uncertainty and imprecision, but also strongly emphasizes the need for further work in this area. This includes the inclusion of other fuzzy approaches in the analysis, change the relative weights of the criteria and their number, and obtain comprehensive answers to the question of which is an adequate method and which provides significant support for decision-making in a wide range of real problems.

ACKNOWLEDGEMENTS

This paper is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through Contract No. 451-03-65/2024-03/200108.

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