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Hybrid Extended Fuzzy AHP and Fuzzy ARAS Methodology for Evaluating Train Organization Systems in Bosnia and Herzegovina

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Abstract

The operational transport strategies of a state are developed as a combination of train organization systems and network usage systems. Due to the central importance of these operational transport strategies, special attention is paid to analyzing their functioning and the conditions under which different combinations of train organization systems and network usage become feasible and commercially viable. This study proposes a hybrid fuzzy approach to multi-criteria decision-making methods for evaluating and assessing train organization systems and network usage in Bosnia and Herzegovina. For this purpose, an extended Fuzzy Analytic Hierarchy Process (E-FAHP) was applied to determine the relative significance of each criterion, followed by ranking train systems using the Fuzzy Additive Ratio Assessment Method (Fuzzy ARAS). To validate the efficacy of the proposed framework, a case study was conducted using a real-world example. The findings demonstrate tangible potential for practical implementation.

Keywords: *railway, train organization, MCDM, extended fuzzy AHP, fuzzy ARAS.*

1. Introduction

Transportation serves as the "nervous system" of a country and stands as one of the most vital cornerstones underpinning the modern economy. It constitutes a critical sector of the economy within the European Union, employing approximately ten million individuals and accounting for around five percent of the total gross domestic product [1]. The transportation sector, which relies heavily on fossil fuels, has experienced the fastest increase in energy consumption (13% from 1998 to 2008) and accounts for 32% of the total final energy consumption. [2]. The European Commission, through its White Paper of 2001, emphasized the development of modal shift from road transport to more economical modes of transportation such as railways and inland waterways [3]. The White Paper from 2011 on transportation defined a strategy for improving the efficiency of the transport sector by introducing advanced transport management systems across all modes of transport, investing in transport infrastructure, and creating a unified transport space to promote the development of intermodal transport. This includes intelligent pricing, energy efficiency standards for all vehicles used in transportation, and other measures aimed at enhancing innovation in the field of transportation [4]. Intermodal transport, as a distinct mode of transportation with its advantages over other modes, plays a significant role in freight transportation in European Union countries. The efficiency of intermodal transport is observed through the efficiency of the transport network, terminals, and freight transport services. The European Union has developed plans and actions to promote intermodal transport, as well as measures for investing significant financial resources. Bosnia and Herzegovina needs to align its transport policy with the objectives of European transport policy and establish a sustainable transport system that would meet the economic, social, and environmental needs of society. Current trends and anticipated future challenges indicate the need to meet the growing demand for "accessibility" while increasing concerns about sustainable development of the transport system. The first priority is better integration of different modes of transport to improve the quality, overall efficiency of the transport system, and accelerate the development and application of innovative technologies. This integration is carried out within processes that always place users and workers in the transport sector and their needs and rights at the center of decision-making processes. When analyzing the quality of intermodal transport, instead of focusing on one aspect of its functioning, it is necessary to apply a comprehensive approach. It is essential to demonstrate the relationship between the supply and demand of intermodal transport,

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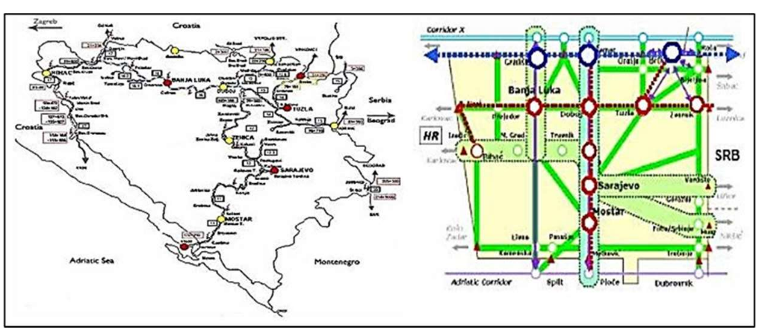
analyze intermodal systems in terms of interactions between all key elements, including terminal operations, train organization systems, and operator strategies in different market conditions. The focus of this research is on the evaluation and selection of train organization systems on the network in Bosnia and Herzegovina. A methodological framework is proposed that combines Multi-Criteria Decision Methods (MCDM), the Extended Fuzzy Analytic Hierarchy Process (E-FAHP) and Fuzzy Additive Ratio Assessment Method (F-ARAS), enabling a comprehensive assessment of efficiency and selection of the optimal train organization in specific contexts of the transport network in B&H.

The rest of the paper is organized as follows: in the second section, an explanation of the problem, alternatives, and criteria, including sub-criteria, is provided. The third section offers a review of relevant literature employing Multi-Criteria Decision-Making (MCDM) methods. The fourth section details the proposed methodological framework for evaluating and selecting train organization systems. Section five presents the results of applying the methodological framework and analyzes the obtained results. Last, section six concludes the paper and suggests directions for future research.

2. Problem Statement

The future development of transport volume largely depends on economic growth and transport policy. It is difficult to imagine that the European economy will not continue to develop, which will also positively impact the economy of Bosnia and Herzegovina as a country on the path to EU membership. Economic development entails an increasing volume of transportation, which, no matter how significant, requires an efficient organization of transport in response. Based on a study on intermodal transport in Bosnia and Herzegovina conducted by the European Union in 2006, it was defined that Bosnia and Herzegovina will have five intermodal terminals in the initial phases of introducing intermodal services [5]: the terminals are as follows: Ploče (considered a "BH terminal" as it mainly serves the area of Bosnia and Herzegovina); Sarajevo (the largest agglomeration); Banja Luka (the capital of Republika Srpska and the second-largest agglomeration); Tuzla (the third-largest agglomeration and an industrial zone); Brčko (a trimodal terminal on the river Sava, a local self-government unit). These terminals are primarily located along three transport corridors: the Sava River, which is connected to Corridor VII; Corridor Vc (Ploče – Sarajevo – Šamac); and the parallel of Corridor X Banja Luka – Doboj – Tuzla – Zvornik. These corridors (Vc, VII, and X) are an integral part of the EU's core transport network. The geographic locations of these five potential terminals encompass the main economic areas and parts of Bosnia and Herzegovina (Figure 1).

Finding solutions is easiest when freight volumes are large, stable, and concentrated on specific corridors, when transport distances are long, and when the demand for service quality is low. However, when freight volumes are smaller, variable, and geographically dispersed, when transport distances are shorter, and when there is a higher demand for service quality, the task becomes much more complicated, as is the case with the transportation system in Bosnia and Herzegovina. The solution to efficiently integrate transport chains to perform transportation effectively and flexibly respond to demand to avoid investment risks is an efficient combination of train organization systems and network usage systems. The goal is to offer adequate services through train organization systems and network usage systems. The European Commission, in its final report on the quality of intermodal transport, defined feasibility criteria for various train organization systems (Table 1). Solutions for different problems in organizing rail combined transport are different train train organization, each with its advantages and disadvantages (Table 2).



Note: Red - highest priorities, yellow - medium priorities

Figure 1. Proposal for the terminal network in Bosnia and Herzegovina [6].

Table 1. Criteria (sub-criteria) of train organization systems. [7]

Feasibility criteria of different train organization systems					
Train organization system	Gateway systems with shuttle and the Y-shuttle by trains	HUB systems with shuttle and Y-shuttle trains	Direct block and shared trains	HUB systems with block and split trains	Line trains
Operating conditions					
Market structure annual traffic volume ETU (***European Transport** Unit*)	20,000	10-20,000	10-20,000	10,000	5,000
traffic stability	very important	very important	important	it does not matter	it does not matter
Operational aspects - distance (km) - terminal availability - equipment flexibility	500 very important very important	200 very important very important	300 it's not that important it's not that important	200 it does not matter it does not matter	100-200 important important
Quality indicators					
- frequency of service	6 trains weekly	1 train per day	3 trains weekly	1 train per day	3 trains weekly
- reliability	very reliable	very reliable	reliably	reliably	not so reliable

Table 2. Train organization systems. [7]

Train organization systems	
Shuttle trains	Direct trains with a fixed composition (the same number of cars on each journey) that run between two terminals (terminal A and terminal B).
Y-shuttle trains	Fixed composition trains comprising two sets of cars. The train leaves Terminal A, and then shunting takes place in the technical stations and we get two sets of cars. These sets travel separately as shorter trains to two different destination terminals B and C.
Block trains	Direct trains with a variable number of cars in the composition that run between two terminals (terminal A and terminal B).
Split trains	Trains with variable car composition, with two or more sets of cars having two or more different destinations.
Line trains	Trains with fixed traffic flows serving several terminals. Trains are loaded and unloaded according to schedule, at terminals along the journey.
Local trains	Trains that move over short distances (along the line or circling) and that represent local terminal servicing.
A train with one car	One intermodal car attached to a conventional freight train.

Shuttle trains are the simplest solution of all. They allow for short turnaround times and low costs since there are no shunting operations involved. Shuttle trains are even used for distances shorter than 200 km. They require a high and stable traffic volume between two terminals. Since this type of service is of high frequency and the train compositions are consistently the same, there is a risk of trains running empty. The simplicity and low operating costs must therefore be balanced against the risk of low cargo loadings.

Y-shuttle trains offer solutions for flows that are stable but of lower volume than required for direct and shuttle trains. Here, train turnaround times are longer, and there are also operating costs in the technical shunting station where the composition is divided into two shorter trains for two different destination terminals.

Block and split trains are considerably more flexible. They offer solutions for corridors with unstable and low traffic volume. At the carriage management level, unfixed train compositions allow operational flexibility to adjust to traffic volume and structure. Block and split trains require train monitoring, and shunting operations incur additional costs.

For the organization of container transport technology as one of the fundamental technologies of intermodal transport, in addition to various train organization systems, the following network usage concepts are applied:

- Isolated corridors often serve major ports or are intended for transportation between connected industrial nodes/factories. Technology A, i.e., "movable highways," emerges as a possible organization of isolated corridors. Since the infrastructure links between industrial corridors are limited, they can hardly be considered a suitable solution for establishing real network access.
- Y-systems serve three terminals with higher traffic intensity. This system is organized through hubs where transshipment/shunting takes place.
- Gateway systems are used as links between national and international flows. These systems also serve as cargo accumulation points for local-level flows. Such organizational systems are an addition to direct shuttle trains and allow for the establishment of Y-shuttle trains, block and split trains. This concept reduces the commercial limitation to serving only two terminals and mitigates the inflexibility of constant train compositions.
- Hub systems involve a central terminal where trains from multiple directions are received and processed. The hub terminal is not the final destination but only a place of consolidation and redirection of incoming trains. Hub systems have been recognized as the most impactful form of intermodal transport development in recent years. The advantages of this organization primarily lie in enabling high "industrialization" of the transport process, thereby improving operational reliability. In addition, these systems can serve as an alternative to the previously mentioned system (Gateway system) in case the traffic volume is insufficient for full shuttle train service.
- The Appendix approach is the oldest approach to organizing intermodal transport but still has very wide application. This approach integrates intermodal wagons into conventional trains. The transit times of these trains as well as quality standards are low, but these issues are compensated for by low operational costs and high frequency of these trains..

3. Literature Review of Hybrid MCDMs Applications

Multi-Criteria Decision Methods (MCDM) are widely used for decision-making in situations where various criteria or factors need to be considered. The essence of MCDM lies in enabling decision-makers to systematically consider different aspects of the problem and their impact on the final decision. This includes identifying relevant criteria, ranking them by importance, and evaluating available options according to these criteria [8]. The application of MCDM can enhance the quality of decisions by making them clearer, more rational, and more efficient. This methodology is particularly useful in situations where the environment is complex and there are numerous potential options to consider. When applied to the evaluation of train organization systems and network usage, MCDM enables a systematic examination of various characteristics and performances of these systems, as well as their effects on operations or processes.

However, the use of MCDM in this context is relatively rare, making research in this area an important step in the development of this method applied to specific problems. Recent studies have shown the effectiveness of hybrid MCDM in various applications, such as location selection [13], measurements of sustainability performance [24], assessments and selection of ships [25] and efficiency of the railway system [22]. Table 3 presents an overview of studies that have utilized MCDM methods in their methodological framework for various purposes. These studies illustrate diverse applications of MCDM in different contexts, highlighting its flexibility and universal applicability across various disciplines. They demonstrate a wide range of situations in which MCDM can be applied, emphasizing its ability to adapt and remain relevant in all stages of decision-making. Their diversity underscores the potential of MCDM to be a powerful tool in making informed decisions in complex and dynamic environments such as the transportation sector.

4. The Proposed Framework for Evaluation and Eelection of Train Organization Systems

The proposed framework is structured into three main phases, as depicted in Figure 2. The first phase focuses on initially determining potential alternatives and defining criteria for the evaluation and selection of alternatives. Subsequently, a hierarchical structure is established with objectives, criteria, and sub-criteria for multi-criteria evaluation. Using the Likert scale, linguistic expressions are transformed into fuzzy numbers. Criterion weights are calculated using the extended fuzzy Analytic Hierarchy Process (E-FAHP) method, utilizing pairwise comparison matrices between criteria and sub-criteria. Fuzzy sets are applied to transform linguistic expression assessments into fuzzy numbers, which are quantitative. Finally, alternative ranking is performed using the fuzzy Additive Ratio Assessment Method (F-ARAS) approach, where each alternative is assessed relative to each criterion.

Table 3. Previous studies with MCDM methods.

Year (References)	Objective	MCDM Models
2012 [9]	Financial performance evaluation of Turkish manufacturing companies	FAHP - VIKOR - TOPSIS
2012 [10]	Integrated assessment of Lithuanian economic	FUZZY TOPSIS – FUZZY VIKOR - FUZZY ARAS
2014 [11]	Financial performance evaluation of six Iranian companies	FAHP – FUZZY VIKOR - FUZZY ARAS - FUZZY COPRAS
2014 [12]	Banking websites quality evaluation	AHP – COPRAS G
2014 [13]	Assessment of priority alternatives for preservation of historic buildings	AHP - ARAS
2014 [14]	Ranking of logistics system scenarios for central business district	FAHP - FTOPSIS
2014 [15]	City logistics concept selection	FUZZY DEMATEL - FUZZY ANP - FUZZY VIKOR
2015 [16]	Ranking of logistics system scenarios	FUZZY AHP - VIKOR
2015 [17]	Green supplier evaluation and selection	FAHP - ARAS-F - MSGP
2016 [18]	Selection best health care insurance	FUZZY AHP - FUZZY TOPSIS
2018 [19]	Framework for multi-criteria evaluation to prioritize Indian railway stations.	AHP - MABAC
2019 [20]	Performance evaluation of green suppliers	ENTROPY-TOPSIS F
2019 [21]	Planning an intermodal terminal for the sustainable transport networks	DELPHI – ANP - QFD
2019 [22]	Efficiency of rail transportation Of Black sea countries	ENTROPY - EATWIOS
2021 [23]	Evaluation of sustainable last mile solutions	DELPHI – FARE - VIKOR
2022 [24]	Evaluation of the smart reverse logistics development scenarios	DELPHI - ANP - COBRA

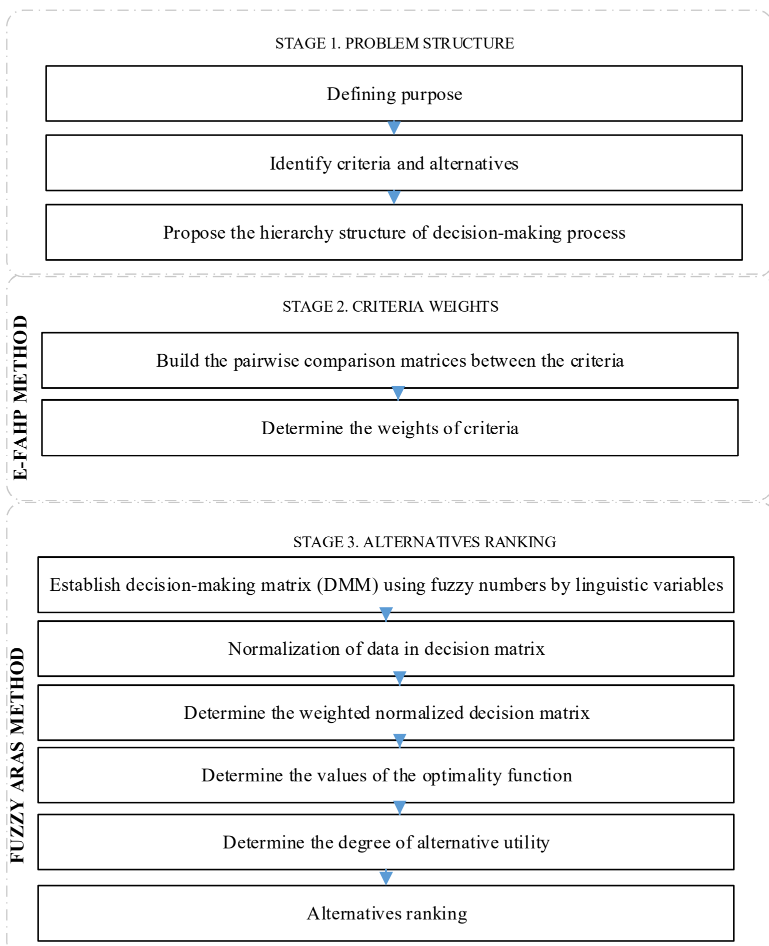


Figure 2. The proposed framework for the decision-making process.

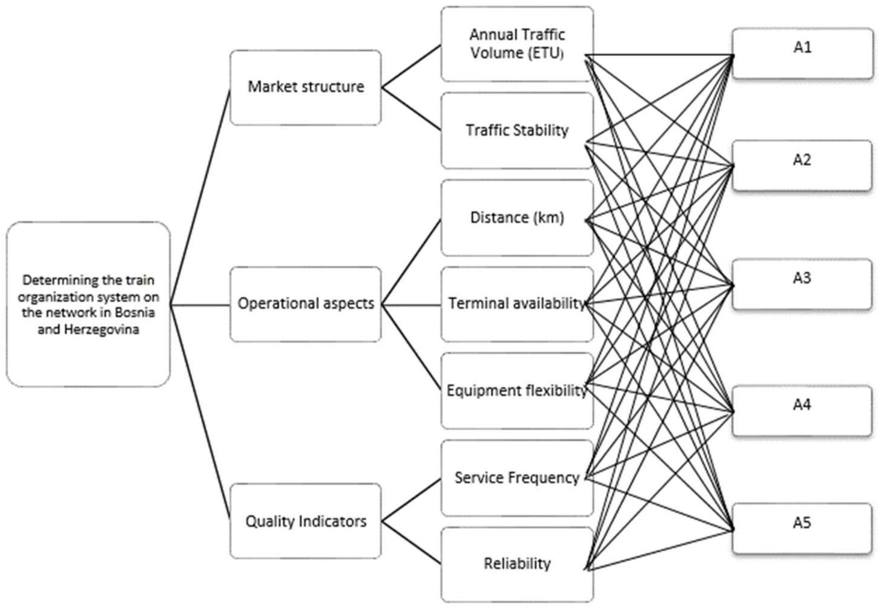


Figure 3. The hierarchical structure of the MCDM for the train organization system evaluation and selection.

The hierarchical structure of the MCDM methodological framework consists of three levels, as depicted in Figure 3: (1) the goal is the selection of train organization systems in the network of Bosnia and Herzegovina; (2) three main criteria considered at this level are market structure, operational aspects, and quality indicators; (3) 7 sub-criteria included in the model for evaluation are annual traffic volume, traffic stability, distance, terminal availability, equipment flexibility, service frequency, and reliability. All criteria and sub-criteria were selectively chosen based on the study. They were carefully selected and validated by an experienced expert.

4.1. Research methodology

4.1.1. Extended fuzzy AHP method

The AHP method enables the creation of a hierarchical structure of criteria to assist decision-makers in focusing on key factors when assigning weights [26],[27]. Characterized by its simplicity and applicability, AHP uses scaling factors to establish pairwise comparison matrices for different alternatives. However, drawbacks of the AHP method include its limited ability to address uncertainties and ambiguities in determining criterion weights based on subjective expert judgments, as well as difficulties in consistently measuring criterion weights in a hierarchical decision-making framework [28]. On the other hand, the fuzzy approach offers its advantages, particularly in handling qualitative and linguistic data. It allows for numerical representation through linguistic variables to describe expert judgments, often employing triangular fuzzy numbers (TFN) due to their simplicity and practicality.

The combination of fuzzy approach and AHP method allows for a more comprehensive utilization of decision-making advantages. Fuzzy AHP integrates the most powerful features of fuzzy logic and AHP, enabling rapid decision-making. Some examples of areas where fuzzy AHP is used include the banking sector [29], assessment of climate change [30], ranking suppliers in manufacturing companies [31], selection of shipyard locations [32]. In this study, criterion weights were obtained using the extended fuzzy AHP method. The extended Chang's fuzzy AHP method combines Chang's approach with the theory of fuzzy sets to enhance the accuracy and efficiency of decision-making in multi-criteria environments [33]. The fuzzy numbers used to evaluate a process in this study are described in Table 4.

Table 4. Linguistic scale for importance.

Linguistic Scale	Triangular Fuzzy Numbers	Reciprocal Values of Triangular Fuzzy Numbers
Equal	1,1,1	1,1,1
Moderate	1/2,1,3/2	2/3,1,2
Strong	3/2,2,5/2	2/5,1/2,2/3
Very Strong	5/2,3,7/2	2/7,1/3,2/5
Extreme	7/2,4,9/2	2/9,1/4,2/7

The E –FAHP was introduced by Chang in both 1992 and 1996, deriving its name from the expansion of Saaty's method as described in Saaty's work from 1985 [34]. Chang's model, outlined in his 1996 publication, can be delineated as follows: it involves a group of objects, X= ($x_1,x_2,x_3,\ldots, x_n$), and a set of objectives, U= ($u_1, u_2,u_3,..,u_n$). In accordance with the extended analysis approach detailed by Chang in 1996 [33], an extended analysis is conducted for each object. Consequently, m values of extended analysis can be derived for each object, utilizing the following notation:

$$M_{gi}^{1}, M_{gi}^{2}, M_{gi}^{m}\text{ , i=1,2…n,} \tag{1}$$

where M_g^j (j = 1, 2, ..., m) are triangular fuzzy numbers.

Key steps in the extended model proposed by Chang (1996) are:

Step 1. The value of i-th object of the extended analysis is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} * \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{2}$$

The value $\sum_{j=1}^{m} M_{gi}^{j}$ can be obtained by adding fuzzy numbers to extended analysis values m for a particular matrix, so that:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{3}$$

Fuzzy numbers $\sum_{j=1}^{m} M_{gi}^{j}$,$j = 1,2,3..m$ must be added for obtaining $\sum_{i=1}^{n}\sum_{i=1}^{m} M_{gi}^{j}$

$$\sum_{i=1}^{n}\sum_{i=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i^x, \sum_{i=1}^{n} m_i^x, \sum_{i=1}^{n} u_i^x\right) \tag{4}$$

The reverse matrix for equation (4), is calculated as:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \frac{1}{\sum_{i=1}^{n} u_i^x}, \frac{1}{\sum_{i=1}^{n} m_i^x}, \frac{1}{\sum_{i=1}^{n} l_i^x} \tag{5}$$

Step 2. The degree of possibility that $M_2 \geq M_1$ is defined as:

$$V(M_1 > M_2) = sup\left[min\left(\mu_{M1}(x), \mu_{M2}(y)\right)\right] \tag{6}$$

When there exists a pair (x, y) such that x≥y and $\mu_{M1}(x)$ =$\mu_{M2}(y)$ = 1 then V(M1 ≥ M2) = 1. Since M1 and M2 are convex fuzzy numbers, therefore V(M1 ≥ M2) = 1 if $m_1 \geq m_2$

$$V(M2 \geq M1) = hgt\ (M1 \cap M2) = \mu_{M1}(d)$$

$$\mu_{M1}(d) = \begin{Bmatrix} 1, & m_2 \geq m_1 \\ 0, & l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{Bmatrix} \tag{7}$$

where d is the ordinate of the highest intersection point D located between μ_{M1} and μ_{M2} (Figure 4) For comparing M_1 i M_2, both values of the expressions V($M_1 > M_2$) and V($M_2 > M_1$) are needed.

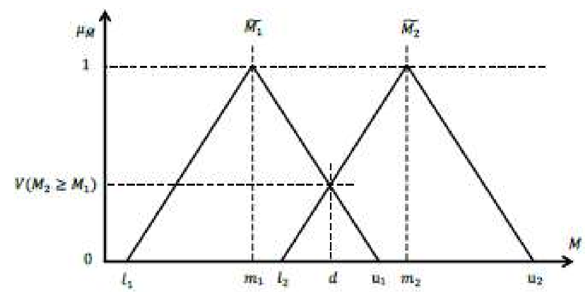


Figure 4. Intersection point between $\widetilde{M_1}$ and $\widetilde{M_2}$ [35].

Step 3. The degree of possibility that a convex fuzzy number will be higher than k convex numbers M_i $(i = 1,2,3, \ldots, k)$ is defined as:

$$V(M \geq M_1, M_2, \ldots . M_k = V[(M \geq M_1)\ i\ (M \geq M_2) i \ldots . i(M \geq M_k)] = minV(M \geq M_i),\ i = 1,2,..k \tag{8}$$

Then, by assuming that:

$$d^{"}(A_i) = \min V\ (S_i \geq S_k)\ , k = 1,2, \ldots n, k \neq i \tag{9}$$

The weight vector is:

$$W^{"} = \left(d^{"}(A_1),\right)d^{"}(A_2), \ldots ., d^{"}(A_n)^T \tag{10}$$

where A_i (i=1,2,3,…n) are n elements.

Step 4. The normalised weight vector is:

$$W = (d(A_1),)d(A_2), \ldots ., d(A_n)^T \tag{11}$$

where W is not a fuzzy number but the set of weights for each matrix.

4.1.2. Fuzzy ARAS

The fuzzy ARAS method involves comparing each alternative with an ideal hypothetical one [8]. The expert use the linguistic terms in Table 5 to evaluate the alternatives with respect to each sub-criterion.

Table 5. The linguistic terms used to evaluate the alternatives [36].

Symbol	Linguistic Scale	Triangular Fuzzy Numbers
VG	Very Good	(0.9, 1.0, 1.0)
G	Good	(0.7, 0.9, 1.0)
MG	Medium Good	(0.5, 0.7, 0.9)
MG	Medium	(0.3, 0.5, 0.7)
MP	Medium Poor	(0.1, 0.3, 0.5)
P	Poor	(0.0, 0.1, 0.3)
VP	Very Poor	(0.0, 0.0, 0.1)

Let's consider the fuzzy decision-making matrix $\widetilde{X} = \widetilde{x_{\iota J}}$, where i = 1, 2, ..., m represents the number of alternatives, and j = 1, 2, ..., n represents the number of criteria. Each criterion of the ith alternative is represented by a triangular fuzzy number: $\widetilde{x_{\iota J}} = (x_{ij1}, x_{ij2}, x_{ij3})$. Additionally, each criterion is assigned a respective coefficient of significance $\widetilde{w_J}$, obtained through E-FAHP in this study. Benefit criteria belong to the set of benefit criteria, denoted as B, while cost criteria belong to their respective set, denoted as C. Fuzzy ARAS can be described as follows [37]:

Given $\widetilde{x_{\iota J}} = (x_{ij1}, x_{ij2}, x_{ij3})$ the ideal alternative is described in the following manner:

$$\widetilde{x_{0J}} = \max x_{ij3}, \forall j \in B \;\; \widetilde{x_{0J}} = \min x_{ij1}, \forall j \in C \qquad (12)$$

Subsequently, the normalized values $\widetilde{x_{\iota J}}$ are obtained:

$$\widetilde{x_{\iota J}} = \frac{\widetilde{x_{\iota J}}}{\sum_{i=0}^{m} \widetilde{x_{\iota J}}}, \forall j \in B\, ;\; \widetilde{x_{\iota J}} = \frac{1/\widetilde{x_{\iota J}}}{\sum_{i=0}^{m} 1/\widetilde{x_{\iota J}}}, \forall j \in C \qquad (13)$$

Each $\widetilde{x_{\iota J}}$ is weighted by computing elements of the weighted–normalized matrix:

$$\widetilde{\widetilde{x_{\iota J}}} = \widetilde{x_{\iota J}} * \widetilde{w}_{ij}, \forall j, i \qquad (14)$$

where $\widetilde{w_J}$ is coefficient of significance and $\widetilde{\widetilde{x_{\iota J}}}$ is the weighted–normalized value of the j th criterion of the ith alternative. The overall utility $\widetilde{S_\iota}$ of the ith alternative is computed in the following way:

$$\tilde{S}_i = \sum_{j=1}^{n} x_{ij} \;, \forall i \qquad (15)$$

Since $\tilde{S}_i = (s_{I1}, s_{i2}, s_{i3})$, i=0,1,…,m is fuzzy number, it is nedded to defuzzify $\tilde{S}_i$:

$$\tilde{S}_i = \frac{s_{i1} + s_{i2}, + s_{i3}}{3} \;, \forall i \qquad (16)$$

Finally, the relative utility of the ith alternative K_i is found:

$$K_i = \frac{S_i}{S_0} \;, \forall i \qquad (17)$$

where $K_i \in (0,1)$. The best alternative is found by maximizing value of Ki.

5. Evaluation Process

In this section, the proposed hybrid MCDM framework for the evaluation and selection of train organization systems in Bosnia and Herzegovina was validated. In the first phase, a list of criteria, sub-criteria, and alternatives was formed. An experienced expert was selected based on qualifications and expertise in relevant areas. The pairwise comparison matrices of the criteria and sub-criteria for E-FAHP are provided in Appendix A (Table A1-A4). The decision-making matrix of alternatives with respect to each sub-criterion for F-ARAS is provided in Appendix B (Table B1).

5.1. Results of extended fuzzy AHP

In the initial phase of the E-FAHP analysis, the linguistic expressions used by experts to assess criteria and sub-criteria were translated into fuzzy numbers through the process of fuzzification. Subsequently, by applying formulas (1-11) of the E-FAHP method, the weights of criteria and sub-criteria were obtained. The results are summarized in Table 6, which presents global weight values and sub-criteria weights. An analysis of the results of the E-FAHP method for evaluating train organization system criteria shows that Market structure (0.4119) has been identified as the most significant criterion, suggesting that market structure plays a crucial role in evaluating system performance. Operational aspects (0.3251) also stand out as a significant factor. These results indicate the importance of analyzing market structure and operational aspects in optimizing train organization performance, while maintaining a focus on quality indicators for continuous service improvement.

The results analysis of the E-FAHP method for sub-criteria evaluation of the train organization system shows that Annual Traffic Volume (ETU) (0.4868) and Reliability (0.4868) are rated as the most important sub-criteria. This suggests that annual traffic volume and reliability are key factors in evaluating system performance. Traffic Stability (0.5132) and Service Frequency (0.5132) are also identified as significant sub-criteria. These results indicate the complexity of factors influencing train organization system performance and highlight the need for a balanced approach in analyzing and improving the system.

Table 6. Results of fuzzy weights from the E-FAHP method.

Criteria	Weight	Sub -criteria	Weight	Normalised weight	Rank
Market structure	0,4119	Annual Traffic Volume (ETU)	0,4868	0,2005	2
		Traffic Stability	0,5132	0,2114	1
Operational aspects	0,3251	Distance (km)	0,4119	0,1339	4
		Terminal availability	0,3251	0,1057	6
		Equipment flexibility	0,2630	0,0855	7
Quality indicators	0,2630	Service Frequency	0,5132	0,1350	3
		Reliability	0,4868	0,1281	5

5.2. Results of fuzzy ARAS

The fuzzy ARAS method was applied to rank the train organization systems, with the criterion weights obtained using the E-FAHP method (Table B2). Table 7 shows the results obtained from the fuzzy ARAS method. According to the values of K among the evaluated alternatives, alternative 2, HUB systems with shuttle and Y-shuttle trains, is selected as the best.

Table 7. Results of the F-ARAS method.

Alternatives	Weight	Rank
A1	0,94000	2
A2	0,95600	1
A3	0,74700	3
A4	0,69700	4
A5	0,55000	5

A1 - Gateway Systems with shuttle and Y-shuttle trains
A2 - HUB systems with shuttle and Y-shuttle trains
A3 - Direct block and shared trains
A4 - HUB systems with block and shared trains
A5 - Line trains

The results analysis of the ARAS method for selecting train organization systems indicates that Alternative A2, which involves systems with terminal stations using shuttle and Y-shuttle trains, is ranked highest with a weight of 0.95600. This alternative stands out as the best choice compared to other options, while Alternatives A1 and A3 are also assessed as competitive but with slightly lower weights. Alternative A5 received the lowest weight, suggesting it is less preferred compared to other options. These results guide selecting the optimal train organization system based on preference analysis across different criteria.

6. Conclusion

Multi-criteria decision-making (MCDM) in selecting alternatives is a complex process involving numerous qualitative and quantitative criteria, often characterized by ambiguity and imprecision in the gathered information. For the selection of train organization systems and network utilization in Bosnia and Herzegovina, the study proposes an MCDM framework that integrates fuzzy methods, extended fuzzy AHP, and fuzzy ARAS. This research addresses the complexity of decision-making processes where it is necessary to consider numerous qualitative and quantitative factors, often characterized by ambiguity and imprecision. By using fuzzy numbers to convert qualitative information into precise data, along with the steps of E-FAHP to determine the weights of criteria and sub-criteria, the research provides a systematic approach to decision-making. Particularly noteworthy is the use of E-FAHP as a key element of this framework, which has proven to be extremely effective in addressing uncertainty and providing a structured and efficient way to analyze quantitative and qualitative data. Fuzzy ARAS represents a useful tool for ranking alternatives, and in this study, it was used to rank train organization systems based on the weight values of sub-criteria obtained from the E-FAHP method. The application of such an approach is expected to enhance the efficiency and effectiveness of decision-making processes in the domain of train organization systems, contributing to the improved functioning of infrastructure and operational processes in that sector. Recommendations for further research involve the use of different methodological frameworks to compare results and deepen understanding. The Analytic Network Process (ANP) method can be highlighted as a useful alternative for evaluating and selecting train organization systems, particularly due to the complex and interconnected relationships between various elements of that system. ANP enables the modeling and analysis of these complex relationships through a network structure, thereby providing additional depth in understanding key factors.

Competing Interest Statement

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and Materials Accessibility

All data generated or analysed during this study are included in this article including additional information in the Appendix section.

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Appendix A

Table A1. The pairwise comparison matrix of the criteria with respect to the goals.

	Market structure	Operational aspects	Quality indicators
Market structure	1,1,1	1/2,1,3/2	3/2,2,5/2
Operational aspects	2/3,1,2	1,1,1	1/2,1,3/2
Quality indicators	2/5,1/2,2/3	2/3,1,2	1,1,1

Table A2. The pairwise comparison matrix of sub-criteria with respect to the Market structure criterion.

	Annual Traffic Volume (ETU)	Traffic Stability
Annual Traffic Volume (ETU)	1,1,1	1/2,1,3/2
Traffic Stability	2/3,1,2	1,1,1

Table A3. The pairwise comparison matrix of sub-criteria with respect to the Operational aspects criterion.

	Distance (km)	Terminal availability	Equipment flexibility
Distance (km)	1,1,1	1/2,1,3/2	3/2,2,5/2
Terminal availability	2/3,1,2	1,1,1	1/2,1,3/2
Equipment flexibility	2/5,1/2,2/3	2/3,1,2	1,1,1

Table A4. The pairwise comparison matrix of sub-criteria with respect to the Quality indicators criterion.

	Service Frequency	Reliability
Service Frequency	1	2/3,1,2
Reliability	1/2,1,3/2	1

Appendix B

Table B1. The decision-making matrix of alternatives with respect to each sub-criterion.

CRITERIA/ALTERNATIVE	A1	A2	A3	A4	A5	Weight
Annual Traffic Volume (ETU)	VG	G	G	MG	M	0,201
Traffic Stability	VG	VG	M	MP	P	0,211
Distance (km)	MG	VG	G	MG	M	0,134
Terminal availability	VG	VG	M	MP	G	0,106
Equipment flexibility	VG	VG	G	MP	G	0,086
Service Frequency	VG	VG	G	VG	G	0,135
Reliability	VG	VG	G	G	MG	0,128

Table B2. The weighted normalized decision-making matrix.

C/A	**AT0**			**A1**			**A2**			**A3**			**A4**			**A5**		
C1	0,044	0,050	0,065	0,039	0,050	0,065	0,031	0,045	0,065	0,031	0,045	0,065	0,022	0,035	0,058	0,013	0,025	0,045
C2	0,060	0,073	0,096	0,054	0,073	0,096	0,054	0,073	0,096	0,018	0,036	0,067	0,006	0,022	0,048	0,000	0,007	0,029
C3	0,030	0,035	0,046	0,015	0,025	0,042	0,027	0,035	0,046	0,021	0,032	0,046	0,015	0,025	0,042	0,009	0,018	0,032
C4	0,025	0,029	0,036	0,023	0,029	0,036	0,023	0,029	0,036	0,008	0,014	0,026	0,003	0,009	0,018	0,018	0,026	0,036
C5	0,019	0,021	0,026	0,017	0,021	0,026	0,017	0,021	0,026	0,013	0,019	0,026	0,002	0,006	0,013	0,013	0,019	0,026
C6	0,027	0,028	0,033	0,024	0,028	0,033	0,024	0,028	0,033	0,019	0,025	0,033	0,024	0,028	0,033	0,019	0,025	0,033
C7	0,026	0,028	0,035	0,024	0,028	0,035	0,024	0,028	0,035	0,018	0,026	0,035	0,018	0,026	0,128	0,013	0,020	0,031
Si	0,231	0,264	0,337	0,196	0,254	0,332	0,199	0,259	0,337	0,128	0,197	0,297	0,090	0,150	0,340	0,085	0,140	0,233
Si	0,277			0,261			0,265			0,207			0,193			0,152		
Ki	1			0,940			0,956			0,747			0,697			0,550		