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The Selection of a Possible Organizational Structure of Railway Companies by Application Fuzzy-ARAS Method

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Abstract

The European railway sector doesn't represent a single, generic type of organizational structure. The Directives from the 1990s offer the possibility for national interpretation giving a wide range of organizational structures for European railways. Different organizational structures of railways are present in the European railway market, and all of them are aligned with the national belief of the country - how to manage the railway. This paper focuses on Multi-Criteria Decision Making (MCDM) methods for ranking and selecting organizational structures of railways. In decision-making, we deal with different types of uncertainty and inaccuracy. For this purpose, we need to use some specific tools. In this paper, we use triangular fuzzy numbers to quantify linguistic data. To overcome the complexity of the decision-making problem, we propose the fuzzy Additive Ratio ASsessment (ARAS) method, which also includes linguistic variables and a group approach to decision-making. With the proposed methodology an evaluation of the alternatives to the organization structure of the railway company in Bosnia and Herzegovina is considered. Separation of railway transport from infrastructure management is ranked as the best organizational structure for this company.

Keywords: *railway, fuzzy ARAS, MCDM, organizational structure, triangular fuzzy numbers.*

1. Introduction

Selecting an organizational structure for a complex and robust system such as a railway is a difficult and delicate process. The organizational structure enables the company to achieve its planned strategic goals and to function effectively and efficiently [1]. The European Commission, with Directive 91/440, began the reform of the European railway systems by progressively opening the railway markets to competition. Several legal acts have been adopted at the level of the European Union (EU), which provide for the structural reorganization of the railways to create competition in this area, increase efficiency, and redirect passengers and cargo from competing modes of transport. Following the legislation, the European railway systems had to separate the train operations and the infrastructure (at least in the private department with its accounts) [2]. Although a wide range of organizational structures is represented in the EU and European Free Trade Association (EFTA) countries, three generic organizational models have been preferred: the Integration Model, the Holding Model, and the Separation Model [3]. Countries such as Sweden, Denmark, the Netherlands, Finland, and the United Kingdom, have implemented complete institutional separation; others reorganized the infrastructure and operations into separate subsidiaries within the holding company structure (the German "holding" model); finally, several countries have chosen the separation of key functions (the French model of "separation of key functions" [4].

The methods for ranking and selecting organizational structures of railway companies aligned with the requirements of the European Union are mainly methods that require structured criteria in hierarchical frameworks, the most famous of which is the AHP (Analytic Hierarchical Process) method. The selection of organizational structures of railway companies is a typical multi-attribute problem that includes several qualitative and quantitative factors. In this paper, the fuzzy set theory

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was integrated, which supports the group decision-making approach using language variables and the Additive Ratio ASsessment method (ARAS) of assessing the quantitative relationship between two values. With the ARAS method, each proposed alternative is evaluated according to predetermined criteria, and then a ranking is made by comparing the alternatives to obtain the best results. The ARAS method was proposed by Zavadskas and Turskis [5], as a newly proposed Multi-Criteria Decision Making (MCDM) method. The ARAS method has been applied to solve various decision-making problems, such as choosing the most suitable foundation installation alternative for a building standing on the water-bearing ground. In papers [6], [7], and [8], the ARAS method was used for project selection. To enable the use of fuzzy logic in the ARAS method, which converts approximate information and verbal variables into a mathematically well-defined way that serves to simulate data processing, Turskis, and Zavadskas proposed a fuzzy extension [9] called ARAS-F.

The aim of this work is a better understanding of the operational area when making a strategic decision in the process of selecting a possible organizational structure of railway companies by the requirements of the railway acquis of the European Union. Choosing the organizational structure of railway companies is sometimes very complex because it contains various uncontrolled and unpredictable factors that influence the decision. When making such decisions, it should be very careful and take into account the justification and benefits of those decisions, as well as the support model for decision-making on the choice of the form of organization of the railway company. Several elements can complicate the decision-making process, such as incomplete information and additional qualitative criteria that are often not taken into account. This paper proposes and illustrates a decision-making model for choosing the corresponding structure of a railway company between alternatives proposed by the World Bank.

2. Literature Review

The literature review gives a better insight into the concepts that are the basis of this research and the available applications of the ARAS method and multi-criteria decision-making are explored.

Turskis and Zavadskas [9] developed a fuzzy ARAS method for locating logistics centers. The AHP method was used to determine the weight values of the decision criteria. Turskis and Zavadskas [11] presented a gray ARAS method for solving supplier selection problems. Kutut et al. [12] to preserve the historical-cultural heritage used the AHP-ARAS approach for prioritizing cultural heritage buildings, and Medineckiene et al. [13] applied the AHP-ARAS approach to solving the problem of a sustainable building certification system. Zavadskas et al. [14] combined AHP and fuzzy ARAS methods to rank seaport locations. Liao et al. [15] integrated the AHP-ARAS approach to solving the green supplier selection problem. Streimikiene et al. [16] applied the AHP-ARAS approach to assessing electricity generation technologies in Lithuania. Büyüközkan and Göçer [17] developed an intuitionistic interval-based fuzzy set-based AHP-ARAS approach to support the supplier selection process in a digital supply chain. Rostamzadeh et al. [18] used the fuzzy ARAS method to measure the performance of supply chain management in small and medium-sized enterprises through the criteria of goods quality, damage level, returns, and compliance with the delivery date. Radović et al. [19] proposed the ARAS method for evaluating the performance indicators of transport companies. Fu [20] combined the AHP-ARAS approach and multiple-choice objective programming to rank airline catering service providers.

None of the previously mentioned works clarified the criteria for choosing the concept of the organization of the railway company during its restructuring and alignment with the acquis in the field of railway transport. The MCDM approach based on fuzzy sets for solving the decision-making problem in choosing the organizational structure of a railway company has not been applied in previous research.

3. Problem Definition

The railway sector in Bosnia and Herzegovina is faced with the obligation to fulfill the conditions of the Stabilization and Association Agreement from 2015 signed between the European Union and Bosnia and Herzegovina. There is an obligation to harmonize sectoral policies with EU framework directives and regulations for railways ("EU railway acquis"). As one of the biggest challenges is the restructuring of the existing railway companies to harmonize with the railway acquis of the EU and achieving harmonization requires changes in both structure and processes in the railway sector.

Entity governments, as owners, have various structural options at their disposal to configure the railways by the EU railway acquis. Alternatives of possible organizational structures of railway companies discussed in [10] include considering whether to adopt a group structure with a holding company or separate companies for managing the infrastructure and carrying out transport with independent companies for freight and passenger traffic.

In a complex system of rail transport as part of a continuous intermodal transport chain, all processes take place very quickly to reduce the time of possible waiting/idling of cars, that is the problem Čabrić et al. considered in [21]. The organization of the railway sector and the mutual operational relations between the railway company and the infrastructure manager are very important. The problem of selecting alternative possible organizational structures for railway companies is a decision-making problem based on multiple criteria that provide a framework for evaluating the organizational structure of a railway company using material, non-material and environmental criteria. The World Bank has identified [10] different criteria that can be taken into account in the process of choosing the organizational structure of a railway company.

Earlier, the selection of the organizational structure of any organization, including the railway company, was based on financial measures, which is an important criterion, but not the only one. Later, researchers developed quantitative and qualitative factors for evaluating organizational structure. During the optimal evaluation and selection process of the future organization of the state-owned railway company, in the case of Bosnia and Herzegovina, the owners of the railway company are the governments of the entities, the criterion restructuring for harmonization with the EU railway acquis should be taken into account, as well as economic criteria such as price and quality of service. The appropriate choice of the future organization of the railway company is not an easy task. Because different railway undertaking organizations may perform similarly for different attributes.

4. Methodology

Decision-makers in the decision-making process are often exposed to doubts, problems, and uncertainties. To process such uncertainties and inaccuracies, decision-makers mainly rely on the tools of probability theory, accepting the principle that inaccuracy regardless of its nature is governed by the law of chance. Probability theory is fine for representing an analysis of the stochastic nature of decision-making, but it cannot measure the inaccuracies or uncertainties arising from human behavior, which is neither stochastic nor random. The fundamental role of decision-makers or other involved parties in the decision-making process presents a series of problems that cannot be dealt with properly according to probability theory. Referring in particular to the multi-criteria analysis, this means that the value of certain alternatives to given attributes often cannot be accurately defined because the decision-maker expresses his preferences, evaluations, opinions, and so on in a linguistic sense. To properly deal with these types of uncertainty we can resort to fuzzy logic. In this part of the paper, the basics of fuzzy set and fuzzy logic are presented and the fuzzy ARAS method is presented as a multi-criteria decision-making methodology.

4.1. Fuzzy logic

Fuzzy logic is based on fuzzy sets, which is a set of objects in which there is no clearly expressed or predefined boundary between objects that are or are not members of the set. Each element in the set is associated with a value that indicates the extent to which the element is represented in the set member.

The creator of fuzzy logic is Lotfi Zadeh. In a series of papers, he presented the basics of fuzzy logic [22], [23], [24], and others. These works were the basis for the further continuous development of fuzzy logic. The concept of applying linguistic variables and fuzzy logic is presented in the paper [24] fuzzy numbers are a powerful way to describe the measurement of subjectivity compared to the exact value. A fuzzy set A is defined as a set of ordered pairs:

$$A = \{(x, \mu_A(x)) \mid x \in X, 0 \leq \mu_A(x) \leq 1\} \tag{1}$$

where:

- X is a universal set or a set of considerations based on which fuzzy set A is defined;

- μA(x) is the function of the element x (x∈X) belong to the set A;

The membership function can have any value between 1 and 0. If the value of the function is closer to 1, the membership of element x to set A is higher, and vice versa. Triangular fuzzy numbers A= (α1, α2, α3), (Figure 1), will be used in this paper, where α1 represents the left and, α3 the right distribution of the confidence interval of the fuzzy number A, and α2 represents the point where the function of belonging to the fuzzy number has its maximum value, i.e. the value 1.

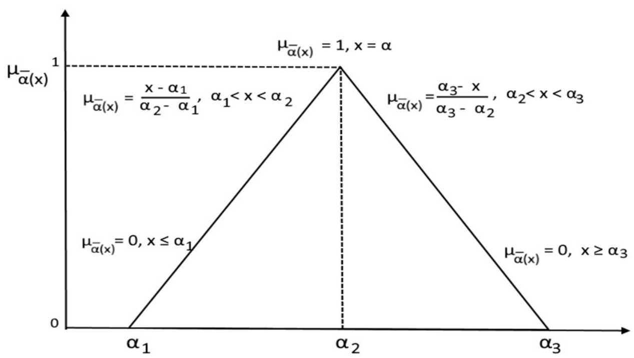

Figure 1. Triangular fuzzy numbers

Linguistic terms and triangular fuzzy numbers were used to evaluate the organizational structure of the railway undertaking. The membership functions of these linguistic variables are shown in Figure 2.

Triangular fuzzy numbers of linguistic variables for criterion weights are shown in Table 1. Performance ranking is shown in Table 2.

Table 1. Linguistic variables for the weights criteria.

Linguistic variables	Fuzzy numbers
Very low (**VL**)	(0, 0, 0.2)
Low (**L**)	(0, 0.2, 0.4)
Medium (**M**)	(0.2, 0.4, 0.6)
High (**H**)	(0.4, 0.6, 0.8)
Very high (**VH**)	(0.6, 0.8, 1)
Extremely high (**EH**)	(0.8, 1, 1)

For example, let U = (VL, L, M, H, VH, EH) be a linguistic set used to express an opinion about a group of attributes (VL = very low, L = low, M = medium, H = high, VH = very high, EH = extremely high).

Table 2. Linguistic variables for the performance ratings.

Linguistic variables	Fuzzy numbers
Very poor (**VP**)	(0, 0, 0.2)
Poor (**P**)	(0, 0.2, 0.4)
Fair (**F**)	(0.2, 0.4, 0.6)
Good (**G**)	(0.4, 0.6, 0.8)
Very good (**VG**)	(0.6, 0.8, 1)
Extremely good (**EG**)	(0.8, 1, 1)

4.2. Steps of the proposed model

Solving decision-making problems using the ARAS method is extended with fuzzy logic that is used to express opinions through linguistic variables that are quantified using triangular fuzzy numbers. Stanujkić [25] showed an extended ARAS method for decision-making problems with triangular fuzzy numbers with an interval value by using the example of the evaluation of university websites. The flowchart of the proposed ARAS approach is given in Figure 3.

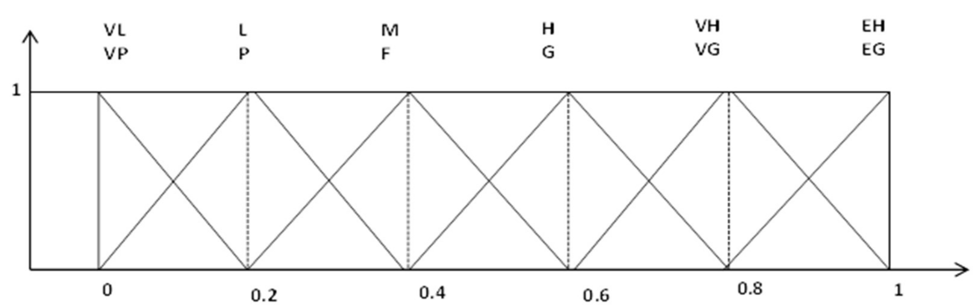

Figure 2. The membership function of linguistic values.

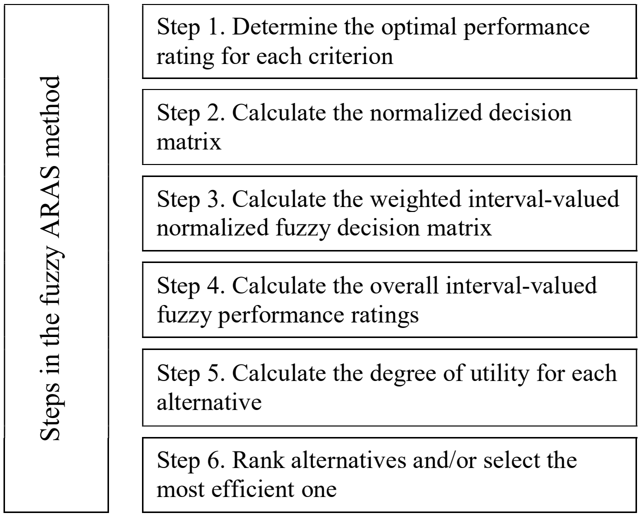

Figure 3. Steps in the fuzzy ARAS method **[25].**

The steps from the workflow are described below.

Step 1. Determine the optimal performance rating for each criterion

When determining the optimal performance rating for each criterion, it is necessary to perform the first modification. Instead of a precise number, the optimal performance rating of each criterion should be an interval-valued fuzzy number, and these optimally interval-valued fuzzy performances are calculated as follows [25]:

$$\tilde{X}_{0j} = \left[\left(l_{0j}, l'_{0j}\right), m_{0j}, \left(u'_{0j}, u_{0j}\right)\right] \quad (2)$$

$\tilde{\boldsymbol{X}}_{\mathbf{0j}}$ – denotes the optimal value of the fuzzy interval of the j-th criterion.

$$l_{0j} = \begin{cases} max_i l_{ij}, & j \in \Omega_{max}, \\ min_i l_{ij}, & j \in \Omega_{min}, \end{cases} \quad (3)$$

$$l_{0j} = \begin{cases} max_i l'_{ij}, & j \in \Omega_{max}, \\ min_i l'_{ij}, & j \in \Omega_{min}, \end{cases} \quad (4)$$

$$m_{0j} = \begin{cases} max_i m_{ij}, & j \in \Omega_{max}, \\ min_i m_{ij}, & j \in \Omega_{min}, \end{cases} \quad (5)$$

$$u'_{0j} = \begin{cases} max_i u'_{ij}, & j \in \Omega_{max}, \\ min_i u'_{ij}, & j \in \Omega_{min}, \end{cases} \quad (6)$$

$$u_{0j} = \begin{cases} max_i u_{ij}, & j \in \Omega_{max}, \\ min_i u_{ij}, & j \in \Omega_{min}, \end{cases} \quad (7)$$

Step 2. Calculate the normalized decision matrix

Calculate the normalized decision matrix. To use the interval of fuzzy number values, it is necessary to make some modifications in the normalization process. Therefore, Eq.(8) can be used:

$$\tilde{r}_{ij} = \begin{cases} \left[\left(\frac{a_{ij}}{c_j^+}, \frac{a'_{ij}}{c_j^+}\right), \frac{b_{ij}}{c_j^+}, \left(\frac{c'_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right)\right]; j \in \Omega_{max}, \\ \left[\left(\frac{1/a_{ij}}{a_j^-}, \frac{1/a'_{ij}}{a_j^-}\right), \frac{1/b_{ij}}{a_j^-}, \left(\frac{1/c'_{ij}}{a_j^-}, \frac{1/c_{ij}}{a_j^-}\right)\right] j \in \Omega_{min}, \end{cases} \quad (8)$$

$\tilde{r}_{ij}$ - denotes the performance evaluation of the normalized interval value of the i-th alternative in relation to the j-th criterion, $i = 0, 1, ..., m$; $c_j^+ = \sum_{i=0}^{m} c_{ij}$; $a_j^- = \sum_{i=0}^{m} 1/a_{ij}$

Step 3. Calculate the weighted interval-valued normalized fuzzy decision matrix

In this step, multiplication is performed on interval triangular fuzzy numbers and can be expressed by Eq. (9).

$$\tilde{v}_{ij} = \tilde{w}_j . \tilde{r}_{ij} \quad (9)$$

$\tilde{\boldsymbol{v}}_{\boldsymbol{ij}}$ - denotes the weighted normalized evaluation of fuzzy performance with an interval value of the *i-th* alternative in relation to the *j-th* criterion (*i = 0, 2,..., m*).

Step 4. Calculate the overall interval-valued fuzzy performance ratings

The overall fuzzy performance ratings with interval values can be calculated using Eq. (10).

$$\tilde{s}_i = \sum_{j=1}^{n} \tilde{v}_{ij} \quad (10)$$

$\tilde{s}_i$ - denotes the overall rating of fuzzy performance with interval values of the ith alternative, i = 0, 1,..., m.

Step 5. Calculate the degree of utility, for each alternative

The degree of utility for each alternative can be determined as the ratio between the degree of utility of the considered alternative and the degree of utility of the optimal alternative, in the manner given in Eq. (11).

$$\tilde{Q}_i = \frac{\tilde{s}_i}{\tilde{s}_O} \quad (11)$$

The results obtained using Eq. (11) are interval-valued fuzzy numbers, and they must be defuzzify. To avoid ranking effects, the obtained overall performance ratings of each alternative should be transformed into exact values before determining the degree of utility. The use of different defuzzification procedures can affect the results obtained, and therefore, apart from the stage of the problem-solving process in which defuzzification is to be performed, the choice of the appropriate defuzzification procedure can also be very important.

Step 6. Rank alternatives and/or select the most efficient one.

The considered alternatives are ranked by the increasing degree of usefulness of the optimal alternative Qi, i.e. the alternative with the highest Qi value is best placed. Therefore, the most acceptable alternative can be determined using Eq. (12).

$$A^* = \{A_i | max_i Q_i\} \quad (12)$$

A^* indicates the most acceptable alternative, $i = 1, 2, \ldots, m$.

5. The selection of a Possible Organizational Structure for Railway Companies

The earlier railway systems of each country were more or less isolated and protected by geographical, institutional, economic, or technical barriers. The evolution of the railway sector from the individual railway systems of each country begins with the railway acquis in 1991. intending to create a Single Railway Area through the removal of technical and institutional barriers. The basic principle on which the railway acquis of the European Union is based is that access to the European railway network should be provided on a non-discriminatory basis, and therefore the infrastructure manager should be independent of the railway companies. There are several ways to achieve this goal.

5.1. Alternative organizational structures of railway companies

Railway companies can be organized in various ways in terms of their ownership, competition between operating companies, traffic specialization, or separated into infrastructure and transport operations. A report by the Research Service of the European Parliament [26] summarizes the established alternative organizational structures of railway companies as three main alternative approaches, namely:

A1) *Separate companies for infrastructure management and transportation.* With this structure, the infrastructure manager and the transport service provider are institutionally and functionally completely independent, whereas the infrastructure manager performs the function of infrastructure capacity distribution. The countries that have adopted this approach are Bulgaria, the Czech Republic, Denmark, Great Britain, Greece, Finland, Netherlands, Norway, Portugal, Romania, Spain, Sweden, and Slovakia.

A2) *Group structure with holding company.* It is an integrated management structure, where the infrastructure manager that grants track access and the railway operator are legally separate companies, thus satisfying the accounting unbundling requirement, but remain within the same institutional structure, for example within, or as a subsidiary of, a holding company. Countries that apply this approach are Austria, Germany, Poland, and Italy.

A3) *Synthesized structure.* This structure requires the establishment of an infrastructure manager responsible for (if independent) the capacity allocation function or (if not independent) subject to the instructions of a separate capacity allocation agency. Countries that apply variants of this structure are Belgium, Estonia, France, Hungary, Latvia, Luxembourg, and Slovenia.

5.2. Defining criteria for assessing a possible organizational structure of railway companies

To identify the organizational structure of railway companies that would be following the EU acquis, while simultaneously taking into account the need to improve the financial sustainability of the railway sector in BiH, the efficiency of certain elements of sector management, and the ease of implementation, it is necessary to define criteria for evaluating the proposed alternatives.

The World Bank in the "Railway Policy Note [10] proposed eight criteria according to which the proposed alternatives were evaluated, namely:

C1) *Ease of implementation*
C2) *Impartiality of the infrastructure manager*

C3) *Clarity and focus of roles*
C4) *The ability of infrastructure managers and operating companies to adopt their business strategies*
C5) *Protection of coordination benefits*
C6) *Administrative efficiency (ministry)*
C7) *Management efficiency (railways)*
C8) *Regulatory efficiency (ministry and RRB)*

6. Application of the Fuzzy ARAS Method

The first step is the ranking of the proposed structures of the organization of the railway company (alternatives) using the fuzzy ARAS method. Using the linguistic variables from Table 1, four evaluators (E1, E2, E3, E4) who assess the weight value of the criteria evaluated the eight selected criteria (C1, C2,..., C8) as shown in Table 3. Similarly, using the linguistic variables from Table 2, four evaluators (E1, E2, E3, E4) evaluated the eight selected criteria (C1, C2,..., C8) for each proposed alternative of the organizational structure of the railway company (A1, A2, A3). A0 is an artificially designed best alternative that is served for selecting the most useful and real alternative from the proposed alternatives (see Table A1 in Appendix). After that, the linguistic variables from Table 3 and Table A1 are transformed into triangular fuzzy numbers. The results of the evaluation of the performance of the organizational structure of the railway company expressed using fuzzy numbers with an interval value, are shown in Table A2 (see Appendix).

Table 3. Weights of criteria were obtained from four evaluators using linguistic variables.

Criteria	E1	E2	E3	E4
C1	EH	VH	H	VH
C2	M	H	H	M
C3	VL	L	M	L
C4	H	VH	M	H
C5	M	L	L	M
C6	M	H	M	VH
C7	VH	H	EH	VH
C8	EH	H	VH	H

Criteria for the evaluation of alternative structures of the organization of railway companies is shown in Figure 4. Determination of optimal performance ratings based on the extended ARAS method proposed in [21] is done using Eq. (1). The obtained ratings of optimal performance are shown in Table A2. The next step is normalization, which is performed using Eq. (7). The normalization result and weighted normalized interval-valued fuzzy ratings of performance, obtained by Eq. (8), are shown in Table A2. Table 4 shows the interval-valued fuzzy rating of performance, obtained by Eq. (9).

Table 4. The overall interval-valued triangular fuzzy performance ratings.

A0	0.77	1.09	1.51	1.82	1.98
A1	0.47	0.74	1.1	1.46	1.7
A2	0.42	0.71	1.09	1.47	1.73
A3	0.03	0.11	0.29	0.51	0.73

To determine the rank of the analyzed proposed alternatives of organizational structures of railway comes, these values must be defuzzify. The Eq. (13) enables a simple determination of the value of the Best Nonfuzzy Performance (BNP) of the interval evaluation of the fuzzy number of analyzed alternatives of the organization of the railway company.

$$gm\tilde{B} = \frac{l + l' + m + u' + u}{5} \quad (13)$$

$$gm\tilde{B} = \frac{(1-\lambda)l + \lambda l' + m + \lambda u' + (1-\lambda)u}{5} \quad (14)$$

$\tilde{B}$ denotes the fuzzy interval value of numbers, λ is the coefficient, a $\lambda \in [0, 1]$. The results obtained by the defuzzification procedure, i.e. using Eq. (13), are shown in Table 5. Also, this table shows the relative quality of the analyzed alternative organizational structure of railway companies aligned with the European railway legislation as well as their ranking order.

Table 5. The degree of utility and ranking order of analyzed organization of railway companies.

Alternatives	BNP	*Qi*	Rank
A0	1,432937		
A1	1,094992	0,764159	1
A2	1,08305	0,755825	2
A3	0,33649	0,234826	3

Table 6 presents the degree of utility and ranking order of analyzed alternatives, for some characteristic of λ.

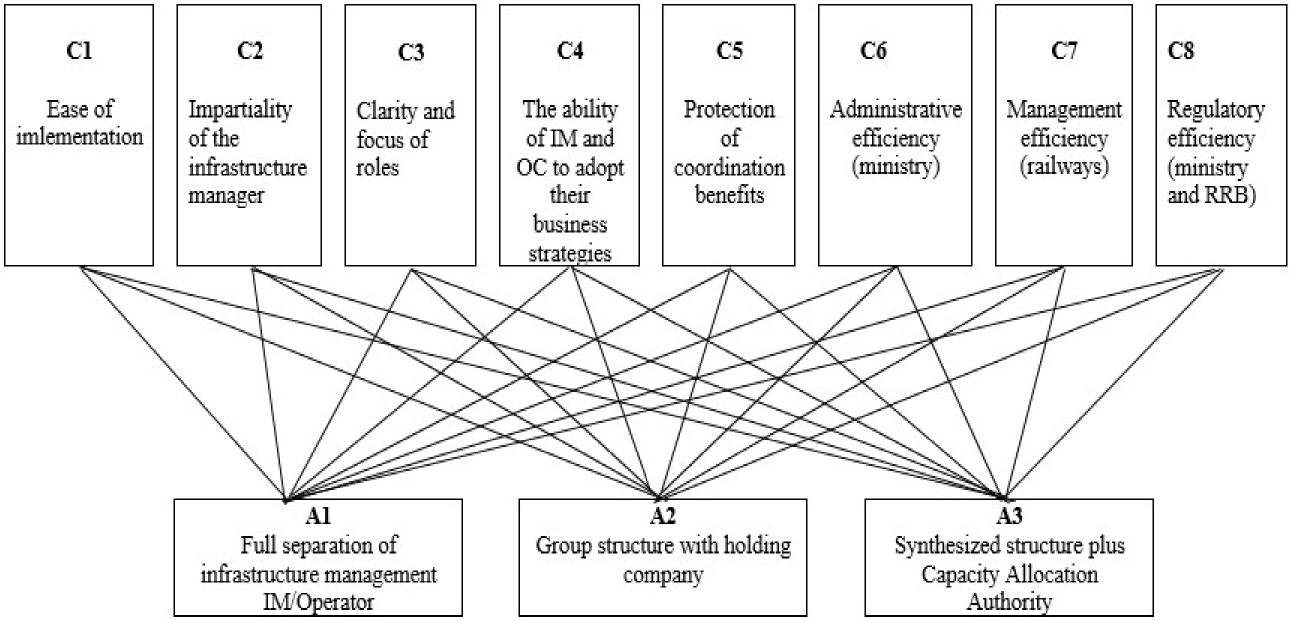

Figure 4. Criteria for the evaluation of alternative structures of the organization of railway companies.

Table 6. The degree of utility and ranking order of analyzed alternatives, for some characteristic of λ.

Alternatives	λ = 0			λ = 0,5			λ = 1		
	Sj	***Qi***	**Rank**	***Sj***	***Qi***	**Rank**	***Sj***	***Qi***	**Rank**
A0	0,851325			0,867138			0,88295		
A1	0,655103	0,76951	**1**	0,657693	0,758464	**1**	0,660283	0,747815	**1**
A2	0,648105	0,761289	**2**	0,65092	0,750654	**2**	0,653735	0,740399	**2**
A3	0,210603	0,247383	**3**	0,197147	0,227354	**3**	0,183692	0,208043	**3**

7. Conclusion

The analysis of experiences of the transformation of individual railway systems points to the conclusion that no single solution has been given in terms of the choice of the organizational structure of the railways, even though more than thirty years have passed since the beginning of the implementation of Directive 91/440/EEC. Due to the existence of different approaches in the process of restructuring national railway companies, adopted regulations, and readiness for the liberalization of the transport market, different organizational structures of railway companies appeared.

The paper presents a methodological framework based on the theory of "fuzzy" sets and the theory of multi-criteria optimization, which enables the selection of the optimal organizational structure of the railways of Bosnia and Herzegovina. Based on the eight proposed criteria and evaluation by four evaluators who come from the railway sector as long-term railway managers and from among experts involved in the process of railway restructuring using the fuzzy ARAS method, alternative A1 – Separation of railway transport from infrastructure management is ranked best.

This paper can help railway companies that are in the restructuring phase to choose an organizational structure that would be harmonized with the legislation of the EU by applying the proposed fuzzy ARAS multi-criteria decision-making method.

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

Supplementary materials and data used in this research are accessible upon request. For access, please contact the corresponding author.

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Appendix

Table A1. Weights of criteria for each alternative were obtained from four evaluators using linguistic variables

Criteria	Alternatives	E1	E2	E3	E4
C1	A1	VP	VP	P	VP
	A2	VG	EG	VG	G
	A3	P	F	G	F
C2	A1	EG	VG	EG	EG
	A2	F	G	F	P
	A3	G	F	F	G
C3	A1	EG	VG	EG	EG
	A2	F	G	F	G
	A3	P	F	P	G
C4	A1	EG	VG	VG	G
	A2	F	P	F	P
	A3	F	G	F	P
C5	A1	F	G	G	F
	A2	VG	G	VG	EG
	A3	F	G	G	P
C6	A1	P	G	F	F
	A2	VG	VG	G	G
	A3	F	P	G	P
C7	A1	EG	VG	G	VG
	A2	G	F	G	VG
	A3	G	F	F	G
C8	A1	VG	EG	EG	VG
	A2	G	F	G	G
	A3	G	G	F	F

Table A2. a) Interval-valued performance rating of organization of railway companies, b) The optimal interval-valued triangular fuzzy performance ratings, c) The normalized interval-valued triangular fuzzy performance ratings, d) The weighted interval-valued triangular fuzzy performance ratings

Criteria	a)			b)	c)				d)				
	A1	A2	A3	A0	A0	A1	A2	A3	Wj	A0	A1	A2	A3
	0.00	0.40	0.00	0.40	0.50	0.00	0.50	0.00	0.40	0.20	0.00	0.20	0.00
	0.00	0.60	0.20	0.60	0.43	0.00	0.43	0.03	0.60	0.26	0.00	0.26	0.02
C1	0.05	0.80	0.40	0.80	0.39	0.02	0.39	0.06	0.80	0.31	0.02	0.31	0.05
	0.25	0.95	0.60	0.95	0.35	0.09	0.35	0.08	0.95	0.33	0.09	0.33	0.08
	0.40	1.00	0.80	1.00	0.31	0.13	0.31	0.10	1.00	0.31	0.13	0.31	0.10
	0.60	0.00	0.20	0.60	0.43	0.43	0.00	0.03	0.20	0.09	0.09	0.00	0.01
	0.75	0.20	0.30	0.75	0.38	0.38	0.10	0.05	0.30	0.11	0.11	0.03	0.01
C2	0.95	0.40	0.50	0.95	0.34	0.34	0.14	0.07	0.50	0.17	0.17	0.07	0.04
	1.00	0.60	0.70	1.00	0.30	0.30	0.18	0.10	0.70	0.21	0.21	0.13	0.07
	1.00	0.80	0.80	1.00	0.28	0.28	0.22	0.11	0.80	0.22	0.22	0.18	0.08
	0.60	0.20	0.00	0.60	0.43	0.43	0.14	0.00	0.00	0.00	0.00	0.00	0.00
	0.75	0.30	0.15	0.75	0.38	0.38	0.15	0.02	0.05	0.02	0.02	0.01	0.00
C3	0.95	0.50	0.35	0.95	0.35	0.35	0.18	0.05	0.20	0.07	0.07	0.04	0.01
	1.00	0.70	0.55	1.00	0.31	0.31	0.22	0.08	0.40	0.12	0.12	0.09	0.03
	1.00	0.80	0.80	1.00	0.28	0.28	0.22	0.11	0.60	0.17	0.17	0.13	0.06
	0.40	0.00	0.00	0.40	0.50	0.50	0.00	0.00	0.20	0.10	0.10	0.00	0.00
	0.60	0.10	0.20	0.60	0.40	0.40	0.07	0.03	0.40	0.16	0.16	0.03	0.01
C4	0.80	0.30	0.40	0.80	0.35	0.35	0.13	0.06	0.60	0.21	0.21	0.08	0.04
	0.95	0.50	0.60	0.95	0.32	0.32	0.17	0.09	0.80	0.25	0.25	0.13	0.07
	1.00	0.60	0.80	1.00	0.29	0.29	0.18	0.11	1.00	0.29	0.29	0.18	0.11
	0.20	0.40	0.00	0.40	0.40	0.20	0.40	0.00	0.00	0.00	0.00	0.00	0.00
	0.30	0.60	0.25	0.60	0.34	0.17	0.34	0.04	0.10	0.03	0.02	0.03	0.00
C5	0.50	0.80	0.45	0.80	0.31	0.20	0.31	0.06	0.30	0.09	0.06	0.09	0.02
	0.70	0.95	0.65	0.95	0.29	0.22	0.29	0.09	0.50	0.15	0.11	0.15	0.04
	0.80	1.00	0.80	1.00	0.28	0.22	0.28	0.10	0.60	0.17	0.13	0.17	0.06
	0.00	0.40	0.00	0.40	0.50	0.00	0.50	0.00	0.20	0.10	0.00	0.10	0.00
	0.20	0.50	0.15	0.50	0.37	0.15	0.37	0.02	0.35	0.13	0.05	0.13	0.01
C6	0.40	0.70	0.35	0.70	0.33	0.19	0.33	0.05	0.55	0.18	0.10	0.18	0.03
	0.60	0.90	0.55	0.90	0.31	0.20	0.31	0.07	0.75	0.23	0.15	0.23	0.06
	0.80	1.00	0.80	1.00	0.28	0.22	0.28	0.10	1.00	0.28	0.22	0.28	0.10
	0.40	0.20	0.20	0.40	0.33	0.33	0.17	0.03	0.40	0.13	0.13	0.07	0.01
	0.60	0.40	0.30	0.60	0.32	0.32	0.21	0.05	0.60	0.19	0.19	0.13	0.03
C7	0.80	0.60	0.50	0.80	0.30	0.30	0.22	0.07	0.80	0.24	0.24	0.18	0.06
	0.95	0.80	0.70	0.95	0.28	0.28	0.24	0.09	0.95	0.27	0.27	0.22	0.09
	1.00	1.00	0.80	1.00	0.26	0.26	0.26	0.10	1.00	0.26	0.26	0.26	0.10
	0.60	0.20	0.20	0.60	0.38	0.38	0.13	0.03	0.40	0.15	0.15	0.05	0.01
	0.70	0.35	0.30	0.70	0.34	0.34	0.17	0.05	0.55	0.19	0.19	0.09	0.03
C8	0.90	0.55	0.50	0.90	0.32	0.32	0.19	0.07	0.75	0.24	0.24	0.14	0.05
	1.00	0.75	0.70	1.00	0.29	0.29	0.22	0.09	0.90	0.26	0.26	0.20	0.08
	1.00	0.80	0.80	1.00	0.28	0.28	0.22	0.11	1.00	0.28	0.28	0.22	0.11