Evaluation of Transport Chain Performance using the IMF SWARA - Fuzzy ROV Model

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Abstract: In modern logistics, transport chains are a strategic success factor for companies, influenced by the demand for fast delivery of goods, digitalization and sustainability. Optimizing these processes requires complex decision making, considering costs, speed, reliability and environmental impact. This paper defines an integrated IMF SWARA and Fuzzy ROV model based on the fuzzy Bonferroni aggregation operator for the analysis of transport chains under conditions of uncertainty. Testing on a case study of the Hygiene Pro Team company shows that the combination of road, sea and rail transport (A3 and A4) yields the best results, while the river alternative (A7) has the lowest ranking. The paper confirms the effectiveness of the fuzzy MCDM approach in balancing economic, operational and sustainability aspects, highlighting the need for further research by incorporating AI and expanded criteria.

Keywords: Transport chains; IMF SWARA; Fuzzy ROV; decision making; logistics

1 Introduction

In today's dynamic business environment, transport chains play a key role in modern logistics [1]. Nowadays, transport is not just the simple movement of goods from one place to another, but a strategic element that directly impacts a company's success. In an era when consumers demand same-day delivery, digital technologies are reshaping the rules of the game and sustainability is becoming a necessity, improving transport chains is no longer an option but a fundamental condition for survival in the market. The functioning of transport chains relies on the coordination of numerous activities, including route planning, selection of transport modes, inventory management, real-time tracking of goods, and coordination among various stakeholders in the supply chain. To meet this demand, constant optimization of transport chains is necessary to achieve higher productivity and lower costs, increase end-user satisfaction, reduce negative environmental impact, and enhance the competitiveness of companies in the market [2, 3]. However, optimizing these processes requires making complex decisions due to multiple factors. Managers must consider costs, speed, reliability, flexibility and sustainability. Changes in demand, fuel prices, regulatory frameworks and technological advances require adaptable decision making models. Classical models often overlook subjective assessments from multiple stakeholders, i.e., interval uncertainty in cost/time estimates and dynamic compromises between economic and environmental factors. In this context, classical decision making methods are often not flexible enough to cover all aspects of the problem. Therefore, multi-criteria decision making (MCDM) methods in combination with fuzzy logic, which enables working with uncertainty and imprecise data, are increasingly being applied [4, 5]. The research contribution in this paper addresses these shortcomings through the innovative integration of IMF SWARA (Improved Fuzzy Step-wise Weight Assessment Ratio Analysis) for determining the weights of criteria, introducing uncertainty and subjectivity through fuzzy logic and the Fuzzy Range of Value (ROV) methodology in ranking alternatives for transport chains based on linguistic values and their quantifications, as well as empirical validation through a case study. The combination of these two methods allows for a more realistic assessment under conditions of uncertainty, which is especially important in the analysis of transport chains, where frequent changes occur in market conditions, legal regulations and technological innovations. The aim of this research is to evaluate and rank alternatives in transport chains using the IMF SWARA and Fuzzy ROV methods, considering key criteria, such as logistics costs, transport chain implementation time, reliability, environmental impact and flexibility. The results will contribute to a better understanding of transport process optimization and provide useful information for managers in decision making. Also, it should be noted that we have integrated these two methods for the first time in the available literature and made a contribution from a methodological aspect.

2 Literature Review

Many problems that arise in logistics processes, particularly within transport chains, can be described as multi-criteria evaluation problems. In order to find the "best" way to reach a specific destination from a given starting point more quickly and efficiently through a multimodal transport network, Qu and Chen [6] presented the potential role of Artificial Neural Network (ANN) theory in the decision making process for multimodal transportation route selection. Based on the theory of the multi-criteria decision making method, the Analytic Hierarchy Process (AHP), and Artificial Neural Network (ANN) theory, they proposed a new hybrid multi-criteria decision making model for selecting routes in multimodal transportation. The proposed model contributes to making route selection in multimodal transport more comprehensive, scientifically supported, fair and accurate. For the selection of dry port terminal location, Tadić et al. [7] developed a new hybrid MCDM model, which combines the Delphi, AHP and CODAS (Combinative Distance-Based Assessment) methods. Majidi et al. [8] considered five major Iranian ports located within specific economic zones and studied their sustainability. In that research, various multi-criteria decision making methods were applied to address the problem of ranking the sustainability of major Iranian ports. Zhang et al. [9] selected 38 cities as candidates for Chinese International Container Intermodal Hubs (CICIH) through qualitative screening, taking into account current China Railway Express (CR Express)/rail-sea intermodal transportation routes and government planning strategies. Subsequently, five connectivity indices were proposed to reflect the performance of hubs across different modes and stages of transport within the logistics chain. The study proposes a hybrid multi-criteria decision making model for comprehensive hub location assessment. Zečević et al. [10] propose a new hybrid MCDM model that combines fuzzy Delphi, fuzzy Delphi based on Fuzzy ANP (fuzzy DENP), and fuzzy Delphi based on fuzzy DVIKOR to address the problem of selecting an intermodal terminal location, involving a large number of criteria that take into account all the requirements and interests of stakeholders, as well as numerous influencing factors. The proposed model provides support for decision-makers in selecting a city logistics concept and is applicable to any city facing logistics challenges, while accounting for its specific characteristics and requirements. The applicability of the approach has been demonstrated on the example of selecting a city logistics concept for the city of Belgrade and its central business zone. Ports, as key nodes in global logistics networks, are becoming increasingly congested. Their capacity for expansion is limited, and traffic in the port hinterland is also becoming congested. As a solution to these and many other issues related to hinterland transport, the development of dry port (DP) terminals is emphasized. The selection of their location is one of the most important strategic decisions, as it directly affects their competitiveness in the market and the functionality of the logistics network. The methods for selecting multimodal transportation routes were also explored by Koohathongsumrit and Chankham

[11]. Their main research question is whether decision-makers need a tool for selecting multimodal freight routes based on both quantitative and qualitative decision-making criteria, including the preferences of the decision makers. This study proposes a novel hybrid approach that integrates fuzzy risk assessment based on the centroid method, fuzzy AHP and VIKOR (multi-criteria optimization and compromise solution). The efficiency and applicability of the proposed approach were verified through an empirical route selection from Thailand to China.

3 Methods

3.1 IMF SWARA Method

Vrtagić et al. [12] developed the Improved fuzzy SWARA method and it includes the following steps, as outlined by Stević et al. [13]:

Step 1: Defining all the criteria used for decision making, and then arranging them in descending order according to their expected importance.

Step 2: Using the ranking established in the previous step, a relatively smaller importance of the criterion (criterion Cj) in relation to the previous one ($Cj-1$) is identified, repeating it for each subsequent criterion. This comparative significance of the average value is denoted by $\overline{s_j}$. An appropriate TFN scale that facilitates accurate and high-quality determination of criteria importance by IMF SWARA is given in Table 1.

Table 1
Scale for evaluating the criteria in the IMF SWARA method

Linguistic Variable	Abbreviation	TFN Scale		
Absolutely less significant	ALS	1	1	1
Dominantly less significant	DLS	1/2	2/3	1
Much less significant	MLS	2/5	1/2	2/3
Really less significant	RLS	1/3	2/5	1/2
Less significant	LS	2/7	1/3	2/5
Moderately less significant	MDLS	1/4	2/7	1/3
Weakly less significant	WLS	2/9	1/4	2/7
Equally significant	ES	0	0	0

Step 3: Determination of the fuzzy coefficient $\overline{k_j}$ (1):

$$\overline{k_j} = \begin{cases} \bar{1} & j = 1 \\ \overline{s_j} \oplus \bar{1} & j > 1 \end{cases} \tag{1}$$

Comparative importance of the average value is denoted by $\overline{s_j}$.

Step 4: Determination of the calculated weights $\overline{q_j}$ (2):

$$\overline{q_j} = \begin{cases} \bar{1} & j = 1 \\ \dfrac{\overline{q_{j-1}}}{\overline{k_j}} & j > 1 \end{cases} \tag{2}$$

$\overline{k_j}$ is a fuzzy coefficient from the previous step.

Step 5: Calculation of the fuzzy weight coefficients by applying Equation (3):

$$\overline{w_j} = \frac{\overline{q_j}}{\sum_{j=1}^{m} \overline{q_j}} \tag{3}$$

where w_j represents the fuzzy relative weight of the criteria j, and m represents the total number of criteria.

3.2 Fuzzy Range of Value Method

The Fuzzy ROV method was developed in [14] for ranking countries based on the Logistics Performance Index.

Step 1. Determining the set of elements of the MCDM model.

Step 2. Creating the fuzzy initial matrix $\aleph_{ij} = \left(\aleph_{ij}^{l}, \aleph_{ij}^{m}, \aleph_{ij}^{u}\right)_{n\times m}$, which is defined based on a linguistic scale after expert evaluation of potential alternatives.

Step 3. Conducting the normalization process, which involves a multi-phase methodology. First, it is necessary to define the elements $\Re_j$ and $\square_j$:

$$\Re_j = \left(\Re_j^{l}, \Re_j^{m}, \Re_j^{u}\right) = \max\left(\aleph_{ij}\right) \tag{4}$$

$$\square_j = \left(\square_{j,}^{l} \square_{j,}^{m} \square_{j,}^{u}\right) = \min\left(\aleph_{ij}\right) \tag{5}$$

After that, calculate the difference between the values in the initial matrix and the minimum value κ_{ij}, and then the difference between the maximum and minimum values of the TFN, denoted as ς_j :

$$\kappa_{ij} = \left(\kappa_{ij}^{l}, \kappa_{ij}^{m}, \kappa_{ij}^{u}\right) = \aleph_{ij} - \square_{j} = \left(\aleph_{ij}^{l} - \square_{j}^{u}, \aleph_{ij}^{m} - \square_{j}^{m}, \aleph_{ij}^{u} - \square_{j}^{l}\right) \tag{6}$$

$$\varsigma_{j} = \left(\varsigma_{j}^{l}, \varsigma_{j}^{m}, \varsigma_{j}^{u}\right) = \Re_{j} - \square_{j} = \left(\Re_{j}^{l} - \square_{j}^{u}, \Re_{j}^{m} - \square_{j}^{m}, \Re_{j}^{u} - \square_{j}^{l}\right) \tag{7}$$

The final normalized fuzzy values are obtained by applying Equation (8):

$$\vartheta_{ij} = \left(\vartheta_{ij}^{l}, \vartheta_{ij}^{m}, \vartheta_{ij}^{u}\right) = 1 + \left(\frac{\kappa_{ij}}{\varsigma_{j}}\right) = \left(\left(1 + \frac{\kappa_{ij}^{l}}{\varsigma_{j}^{u}}\right), \left(1 + \frac{\kappa_{ij}^{m}}{\varsigma_{j}^{m}}\right), \left(1 + \frac{\kappa_{ij}^{u}}{\varsigma_{j}^{l}}\right)\right) \tag{8}$$

In the final fuzzy normalized matrix, there may be situations where the fundamental principles of TFN are not satisfied, so it is necessary to apply:

$$if\ \vartheta_{ij}^{m} \leq, \vartheta_{ij}^{l}\ then\ , \vartheta_{ij}^{m} = \vartheta_{ij}^{l}, \quad if\ \vartheta_{ij}^{u} \leq, \vartheta_{ij}^{m}\ then\ , \vartheta_{ij}^{u} = \vartheta_{ij}^{m} \tag{9}$$

Eqs. (6)-(8) are applied when dealing with benefit criteria, while for cost criteria, the following procedure is applied (10):

$$\vartheta_{ij} = \left(\vartheta_{ij}^{l}, \vartheta_{ij}^{m}, \vartheta_{ij}^{u}\right) = 1 + \left(\frac{\square_{j}}{\aleph_{ij}}\right) = \left(\left(1 + \frac{\square_{j}^{l}}{\aleph_{ij}^{u}}\right), \left(1 + \frac{\square_{j}^{m}}{\aleph_{ij}^{m}}\right), \left(1 + \frac{\square_{j}^{u}}{\aleph_{ij}^{l}}\right)\right) \tag{10}$$

Step 4. Multiply the matrix ϑ_{ij} by the values of the factor w_j.

$$\nu_{ij} = \left(\nu_{ij}^{l}, \nu_{ij}^{m}, \nu_{ij}^{u}\right) = \vartheta_{ij} \otimes w_{j} = \left(\vartheta_{ij}^{l} \otimes w_{j}^{l}, \vartheta_{ij}^{m} \otimes w_{j}^{m}, \vartheta_{ij}^{u} \otimes w_{j}^{u}\right) \tag{11}$$

Step 5. Determine the sums of the previous matrix according to the type of criterion, with values summed separately for *max* criteria T_i^{+}, and separately for *min* criteria T_i^{-}.

$$\mathrm{T}_i^{+} = \sum_{j=1}^{m} \left(\nu_{ij}^{+}\right) \tag{12}$$

$$\mathrm{T}_i^{-} = \sum_{j=1}^{m} \left(\nu_{ij}^{-}\right) \tag{13}$$

Step 6. The alternatives are sorted in descending order:

$$\Lambda_i = \left(\frac{T_i^{+} + T_i^{-}}{2}\right) \tag{14}$$

4 Case Study

4.1 Characteristics of the Hygiene Pro Team Company and its Business Activities

Hygiene Pro Team has grown into a modern, profitable company, and is becoming one of the largest companies in its field. The company's core business involves the trade of paper hygiene goods, cleaning products, and other consumable materials related to hygiene. In order to ensure the distribution of high-quality products, the company has established partnerships with leading global and European manufacturers. Due to its close and sincere relationships with clients, its focus on understanding their unique needs, and the support of an experienced, professional and dedicated team, the company continues to experience consistent growth and business development year after year.

4.2 Defining Alternative Transport Technologies

The number of possible alternatives of transport chains depends on: the number of carriers, the type of intermodal freight units (pallets, containers, swap bodies, etc.), the types of machinery applied in the chain, and the number of available typical transport technologies. Based on transport structures, for land transport technologies, more than 100 possible transport chain alternatives can be generated. Similarly, when considering combinations of intermodal land-water chains, the number of possible alternatives exceeds 1,000. When looking at combinations within land transport technologies for freight units based on road and rail transport, there are two main alternatives of transport chains:

- Direct land transport using road or rail transport vehicles (Figure 1),
- Combined road-rail transport or combined river-road-rail transport (Figure 2).

Direct road transport of freight units (door-to-door) offers significant opportunities and advantages for transport over shorter distances of up to 100 km. This mode of transport is ideal for the transportation of perishable and expensive goods over longer distances, as well as for smaller quantities of goods when no alternative transport modes are available. Direct rail transport can only be implemented if both the sender and the receiver have industrial rail tracks. Depending on the type of train, scheduled trains are most commonly organized (rarely sender's trains, typically closed block trains from terminal to terminal), usually during nighttime hours. This mode of transport offers advantages in terms of cost-efficiency for larger quantities of goods and a lower environmental impact. However, it is limited by the need for specialized infrastructure and has less flexibility compared to road transport. The overall efficiency of both transport modes depends on specific conditions and needs, with the choice being made based on the type of goods, distance and available infrastructure.

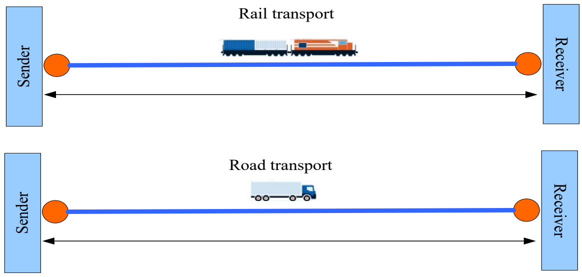

Figure 1
Schematic view of direct land transport

Combined classical land transport refers to the transportation of goods using at least two modes of transport without changing the unit in which the goods are transported. Road transport is mainly used for the pickup and delivery of goods to and from the railway (due to the well-developed road network), while rail transport is used for medium and long distances.

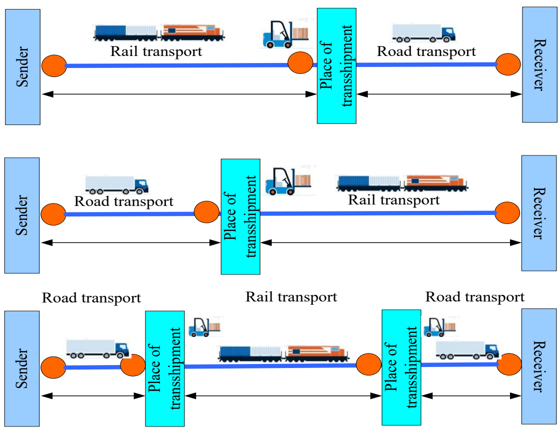

Figure 2
Schematic view of land combined transport

The transport chain can be highly complex, especially involving land-water transport technologies, due to the large number of possible implementation combination. The complexity makes it difficult to describe the chain numerically for the purpose of its optimization. Combined transport technologies typically involve two or more carriers, two or more operators, several types of intermodal freight units, and various organizational forms, all of which highlight the complexity of transport organization. The main objective is to analytically and graphically identify the fundamental forms of transport chains, the structure of the processes within them, the points at which the mode of transport changes, and to determine specific technological timeframes, i.e., the total turnaround time of transport vehicles and/or intermodal freight units.

In this paper, alternatives of transportation technologies are developed by combining various modes of transport throughout the entire transport chain from the Logistics Center in Shanghai to Belgrade and the Hygiene Pro Team company (including road, rail, sea, river transport), as well as different transportation technologies (pallets, containers, swap bodies, Huckepack units, etc.). The starting point of the transport chain is the Logistics Center in Shanghai, while the endpoint is the Hygiene Pro Team company. A breakpoint refers to the location where a change in the mode or technology of transport occurs. The distribution centers in Shanghai and Belgrade are equipped with their own infrastructure. To implement the transport chain, an analysis of the geographical and traffic-related position is necessary. Since the goods are not particularly expensive and delivery is not urgent, air transport will not be considered. Instead, road, sea, river and rail transport will be taken into account. Twenty-foot containers will be used for the transport. The Logistics Center in Shanghai is located 16 km from the Port of Shanghai, while the Hygiene Pro Team company is situated 12 km from the Port of Belgrade and 18 km from the company Railway Integrated Transport (*Železnički integralni transport - ŽIT*). The paper will present several possible alternatives of the transport chain, including:

1) Road - sea - road transport (Port of Thessaloniki) - A1,
2) Road - sea - rail – road transport (Port of Thessaloniki) - A2,
3) Road - sea - road transport (Port of Rijeka) - A3,
4) Road - sea - rail – road transport (Port of Rijeka) - A4,
5) Road - sea- road transport (Port of Koper) - A5,
6) Road - sea - rail - road transport (Port of Koper) - A6,
7) Road - sea - river – road transport (Port of Constanta) - A7,
8) Road - sea - rail - road transport (Port of Constanta) - A8,
9) Rail - road transport from the Logistics Center in Shanghai to the Hygiene Pro Team company in Belgrade - A9.

An illustration of one alternative, i.e., alternative A7, is presented in Figure 3.

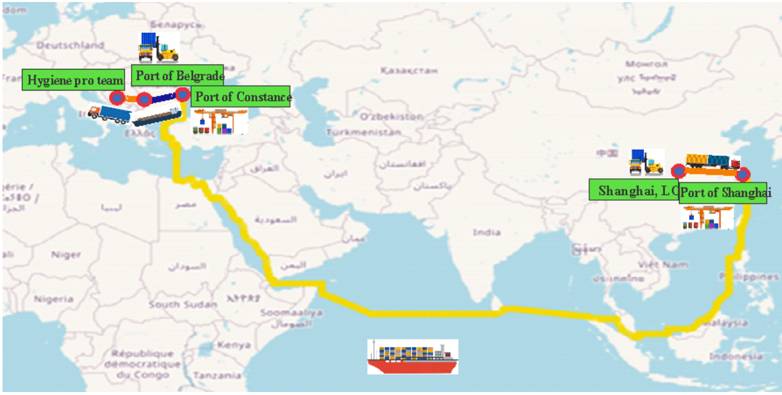

Figure 3
Illustration of the transport chain of alternative A7

4.3 Defining Criteria for Selecting Alternative Transport Chain Technologies

In order to define the criteria, a study was conducted on the most commonly used criteria for evaluating alternative solutions in logistics based on available literature. [15] Taking into account the study conducted, it was concluded that both qualitative and quantitative criteria are used. Quantitative criteria are also mandatory criteria and include logistics costs and transport chain execution time.

Logistics costs (C1). Information about the structure and size of logistics costs is essential for making various types of decisions. The cost characteristic is the first and most significant factor when selecting an alternative transport chain technology. Transport chain execution time (C2). This criterion is also one of the most important criteria. Road transport is globally known as the most reliable mode of transport when it comes to this criterion, especially for cargo or goods that have an expiration date, which is not the case in this study. However, it can still be concluded that this criterion holds a high ranking. In addition to quantitative criteria, there are also qualitative criteria that are determined through descriptive ratings. The qualitative criteria selected for this research are as follows: Flexibility in response to changing logistical requirements, delivery reliability in terms of time, structure and quantity, and emission of harmful gases.

Flexibility in response to changing logistical requirements (C3). This criterion refers to the ability to adapt in the event of changes in requirements in terms of necessary capacities, mobility and elasticity to meet the requested logistical service. Delivery reliability in terms of time, structure and quantity (C4). This criterion is the most significant qualitative characteristic from the user's perspective. The level of reliability is a very important criterion because it is crucial that goods reach their destination on time and in the correct quantity. This largely affects the quality of the delivery itself and the satisfaction of the user, i.e., the end customer. Emission of harmful gases (C5). The environmental aspect represents one of today's biggest challenges. Globally, this is often a conditional criterion for the implementation of a certain transport chain technology alternative. Road vehicles are the ones that contribute most to environmental degradation.

5 Research Results

This section of the paper presents the results of the research. First, the procedure for calculating the weight coefficients of the criteria using the IMF SWARA method and the Fuzzy Bonferroni operator [16, 17] is briefly described. Following this, the initial decision matrix with input parameters and the final evaluation results of the transport chain alternatives, obtained using the Fuzzy ROV method, are presented. The determination of criterion weights using the IMF SWARA method is shown in Table 2, based on the example of one of the five decision-makers. Managers from logistics companies and transport railway and road companies participated in assessing the significance of individual criteria. Manager Hygiene pro team (BSc in traffic engineering - logistics, 7 years of work experience), manager Standar Logistic (BSc in traffic engineering - logistics, 22 years of work experience), manager Milšped Group Belgrade (BSc in traffic engineering - road traffic, 12 years of work experience), manager Combined transport (BSc in traffic engineering - railway, 18 years of work experience) and manager Transagent Belgrade (BSc in traffic engineering - railway, 27 years of work experience).

Table 2

Example of IMF SWARA calculation for determining criterion weights

DM1	sj			kj			qj			wj		
C1				1.000	1.000	1.000	1.000	1.000	1.000	0.290	0.301	0.316
C2	2/9	1/4	2/7	1.222	1.250	1.286	0.778	0.800	0.818	0.226	0.241	0.258
C4	1/4	2/7	1/3	1.250	1.286	1.333	0.583	0.622	0.655	0.169	0.188	0.207
C3	2/9	1/4	2/7	1.222	1.250	1.286	0.454	0.498	0.536	0.132	0.150	0.169
C5	2/9	1/4	2/7	1.222	1.250	1.286	0.353	0.398	0.438	0.102	0.120	0.138
						SUM	3.168	3.318	3.446			

The final criterion weights, calculated using the IMF SWARA method and averaged with the fuzzy Bonferroni operator, are presented below. C1=(0.267,0.276,0.286), C2=(0.242,0.252,0.264), C3=(0.133,0.149,0.166), C4=(0.162,0.178,0.194), C5=(0.128,0.144,0.16) Based on the calculated weights of the criteria, it can be concluded that the first two criteria, which belong to the group of quantitative criteria, have the highest values. The most significant is criterion C1 – logistics costs, followed by C2 – transport chain execution time, while the qualitative criteria are comparatively less important. The following section (Table 3) shows the initial matrix where the quantitative criteria were derived from extensive analysis, while the qualitative ones were obtained by decision-makers' evaluation.

Table 3
Initial decision matrix

	C1	C2	C3	C4	C5
A1	2346	1496.88	7	5	3
A2	2320	1628.57	5	3	5
A3	2042	1552.06	7	7	3
A4	2007	1679.16	5	5	5
A5	2288	1556.46	7	5	3
A6	2147	1682.24	5	3	5
A7	2442	1717.92	3	3	5
A8	3165	1661.57	3	1	7
A9	5737	922.66	1	1	7
	min	min	max	max	max

By applying the complete Fuzzy ROV methodology, the final results were obtained (Table 4), representing the ranking of the transport chain alternatives.

Table 4
Results of applied IMF SWARA - Fuzzy ROV model

				DF	
A1	1.055	1.542	3.026	1.708	**5**
A2	0.963	1.391	2.728	1.543	**6**
A3	1.188	1.616	3.217	1.812	**1**
A4	1.150	1.618	3.113	1.789	**2**
A5	1.121	1.527	3.122	1.725	**3**
A6	1.083	1.549	3.017	1.716	**4**
A7	0.918	1.258	2.562	1.419	**9**
A8	0.961	1.344	2.722	1.510	**8**
A9	0.957	1.394	2.699	1.538	**7**

Based on the results shown in Table 4 and the ranking of transport chain alternatives, the road - sea - road transport (Port of Rijeka) - A3 and road - sea - rail - road transport (Port of Rijeka) - A4 represent the most suitable alternatives for the observed company. To verify the obtained results, a comparative analysis was conducted using the following methods: Fuzzy Objective Pairwise Adjusted Ratio Analysis (Fuzzy OPARA) [18], Fuzzy Measurement Alternatives and Ranking according to Compromise Solution (Fuzzy MARCOS) [19], Fuzzy Simple

Additive Weighting (Fuzzy SAW) [20], and Fuzzy Weighted Aggregated Sum Product Assessment (Fuzzy WASPAS) [21].

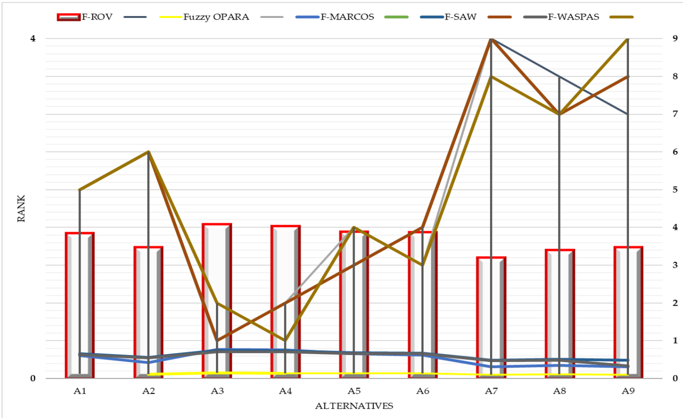

Figure 4
Results of comparative analysis

The results of the comparative analysis show the stability of the initial findings obtained using the IMF SWAFA - Fuzzy ROV model, further supported by the calculation of the correlation coefficients SCC [22] and WS [23, 24]. The original model demonstrated the following correlations in the comparative analysis: SCC: 0.967, 0.983, 0.983, 0.917 and WS: 0.965, 0.998, 0.998, 0.865, respectively for the applied fuzzy MCDM methods.

Conclusions

The optimization of transport chains represents a key success factor, particularly in the context of increasing demands for delivery speed, sustainability and flexibility. This research presents the application of the IMF SWARA and Fuzzy ROV methods for evaluating and ranking alternatives in transport chains, taking into account dynamic conditions of uncertainty and subjectivity. Through a case study of the Hygiene Pro Team company, nine transport chain alternatives were analyzed, combining various modes and technologies of transportation. The IMF SWARA method was used to determine the weights of the criteria. The Fuzzy ROV method enabled the ranking of alternatives, with alternatives A3 (road-sea-road transport via the Port of Rijeka) and A4 (road-sea-rail-road transport via the Port of Rijeka) obtaining the best results, while A7 (road-sea-river-road transport via the Port of Constanta) was the least favorable. The research findings confirm that the combination of the IMF SWARA and Fuzzy ROV methods provides a strong and adaptable framework for decision making under conditions of uncertainty, allowing for a balance between economic profitability, environmental sustainability and operational efficiency. The application of these methods has enabled a more realistic assessment of subjective criteria, such as flexibility and reliability. Future research should focus on expanding the model with new criteria (e.g., risk of delays, digitalization), applying it in other industries, and integrating it with AI tools for dynamic adaptation to changes in the supply chain. In an era of escalating disruptive factors – from climate crises to volatile markets – the application of adaptive MCDM models is not just a competitive advantage but a necessity for the sustainable survival of companies in an open market. In order to meet the challenges of the 21st Century, the integration of science, technology, and strategic management is becoming the foundation for transforming logistics processes.

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