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A Comprehensive Decision Framework for Selecting Distribution Center Locations: A Hybrid Improved Fuzzy SWARA and Fuzzy CRADIS Approach

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Abstract: The focus of this study is on the significance of location in establishing distribution centers. The key question when selecting a location is regarding which location would contribute the most to the growth of a company's business through the establishment of distribution centers. To answer this question, we conducted research in the Brčko District of BiH in order to determine the best location for a distribution center using expert decision-making based on linguistic values. In order to use these values when selecting locations, a fuzzy set was formed using the IMF SWARA (Improved Fuzzy Stepwise Weight Assessment Ratio Analysis) and fuzzy CRADIS (Compromise Ranking of Alternatives from Distance to the Ideal Solution) methods. The IMF SWARA method was utilized to determine the weights of the criteria, and the fuzzy CRADIS method was employed to rank the locations based on expert ratings. The location for the construction of distribution centers at Bodarište was rated the worst, while the McGowern Base location was rated the best. Based on these findings, the research question was answered, and it was demonstrated that fuzzy methods could be utilized in the selection of distribution center locations. Hence, we recommend that future research be performed on the application of fuzzy methods in the expert selection of potential sites for distribution centers.

Keywords: distribution center; location; fuzzy methods; Brčko District of BiH

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1. Introduction

Given that transportation significantly contributes to urban air pollution and that lowering urban city pollutants is crucial, sustainable development, a green economy, and green growth [1] are all closely related to sustainable transportation. The pollutants emitted by on-road transportation place a significant burden on the scenario of climate change as most developing nations primarily use diesel-run vehicles for transportation [2]. Furthermore, retrofitting existing infrastructure presents a major opportunity to decrease global energy consumption and advance sustainable development [3].

The need for transportation of different goods has unquestionably grown significantly as urban areas have become denser and consumer demand has skyrocketed. In terms of traffic volume, noise pollution, air quality, and road damage, the growth of transportation activity has had a negative effect on urban residents and the environment [4]. Distribution centers, whether urban or regional, emerge as the most popular alternative among potential interventions to reduce and/or make more efficient urban transportation activity [5] by combining freight movements. To define a distribution center, we could describe the term as a place where products are transshipped, where deliveries are combined, and where the distribution process is effectively carried out [6]. The term "distribution center" refers to a specifically designated neighborhood that is close to markets and transportation hubs. According to the type and durability of the products, distribution centers facilitate well-organized storage and distribution [7]. Distribution centers are being created based on social, economic, geographical, and many other factors, and there are numerous examples of these facilities throughout the world.

One of the main issues could be selecting one from a possible variety of locations for a distribution center while considering and meeting a set of requirements. The primary consideration in the decision-making process is defining the criteria that will determine the distribution center's location and, in doing so, decision makers must consider the competing interests of various stakeholders. With the support of multi-criteria decision analysis, stakeholders can examine and weigh the different aspects they believe to be important for sound decision-making [8]. These aspects could be intangible, such as security or environmental impact, or they could be tangible, such as different costs, infrastructure condition, and distances to o from important locations.

This paper focuses on the Brčko District of Bosnia and Herzegovina (BiH), a local community in the country's northeast that shares borders with the Republic of Croatia and is close to the Republic of Serbia. As the Brčko District government recognizes the community's strategic location and has invested in the development of business zones to capitalize on its potential, this study evaluates these business zones in order to identify the best zone for companies looking to establish distribution centers in the area. The primary goal of this research is to provide a thorough evaluation of these locations in order to assist companies in making informed decisions about the establishment of distribution centers. Thus, in order to accomplish this, this study employs multi-criteria decision-making (MCDM) methods to evaluate potential locations in BiH's Brčko District.

One could argue that MCDM approaches, when applied to location selection challenges [9], can assist decision makers by providing an objective and methodical evaluation of alternatives based on a range of criteria. In this light, this paper aims to optimize every aspect of the supply chain and meet all the criteria for selecting the most suitable location for a distribution center. We will use an expert assessment based on linguistic values to select the location for the distribution center. To achieve this, this paper will employ the fuzzy set-based IMF SWARA (Improved Fuzzy Stepwise Weight Assessment Ratio Analysis) and fuzzy CRADIS (Compromise Ranking of Alternatives from Distance to the Ideal Solution) methods. The IMF SWARA method will calculate the weights of the criteria, and the fuzzy CRADIS method will be used to rank the alternatives.

This paper is designed to address several key research gaps, including (1) evaluating potential distribution center locations in BiH's Brčko District and (2) proposing a hybrid methodology that employs a fuzzy set approach to facilitate the selection of these distribution center locations. Finally, by providing a comprehensive evaluation of potential locations within the Brčko District, this research aims to provide (3) guidance to potential investors interested in establishing distribution centers.

Following the introduction, this paper consists of a literature review focused on the use of different MCDM methods, the application of group decision-making (GDM), and selection criteria used in the subject of the research. Following the Methodology section that presents the approach taken in this paper, the Results section evaluates the weights of the criteria and the rankings of locations that will aid in selecting the location for the establishment of distribution centers. Section 5, Discussion, provides a more detailed examination of the research results and, finally, Section 6, Conclusion, summarizes the most important research results, limitations of this research, and recommendations for future research.

2. Literature Review

Numerous academic research articles have been devoted to analyzing the potential use of MCDM methods in various fields of life and science [10]. However, this research paper focuses on decision-making issues related to the selection of distribution center locations.

To begin, scientific articles that used MCDM/MCDA (multiple-criteria decision analysis) methods to address global location selection issues for distribution centers were considered. The primary search criteria used to identify these articles were MCDM, MCDA, distribution and logistics center, and various MCDM/MCDA approaches and methods. According to the literature reviewed, the three most commonly used methods were Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). AHP, developed by Saaty [11], is a technique that combines mathematics and psychology to organize and evaluate complex decisions. By representing decision criteria and potential outcomes numerically and linking them to the main objective, AHP provides a logical framework for making necessary decisions. ANP is a mathematical theory developed by Saaty [12] that is useful for predicting and displaying the influence of various decision criteria, their interactions, and relative weights. ANP has been successfully applied in various fields [13]. The TOPSIS method was created by Hwang and Yoon [14] to solve problems involving MCDM. TOPSIS is based on the notion that the selected alternative should be closest to the positive ideal solution while being farthest away from the negative ideal solution. To address location selection questions in different scenarios, several studies utilized the AHP in its basic variant, along with Fuzzy AHP and a Spherical Fuzzy (SF) AHP as part of the selection process [4,15–23]. Additionally, ANP and Fuzzy ANP were identified as useful methods [7,18,24,25], as well as TOPSIS, Fuzzy TOPSIS, and the Single-Valued Complex Neutrosophic Set (SVCNS) variant of TOPSIS [4,15,19,20,24–28].

Next, recent literature has investigated the application of GDM to sustainable development, which is a major concern for the distribution and shipping industries. Yang et al. [29] conducted an analysis of the specific applications of GDM methods in Shipping Industry 4.0 and explored potential future research directions. The authors suggest that research in this field will continue to grow in the future as the development of Shipping Industry 4.0 can improve shipping-related enterprises' ability to respond to market trends, reduce operating costs throughout the shipping industry chain, and accelerate overall development [29]. To address multi-criteria sorting (MCS) problems in the context of MCS-GDM problems, Zhang and Li [30] proposed two consensus-based TOPSIS-Sort-B (boundary profiles) algorithms. The authors argue that practical issues call for the involvement of multiple experts to achieve consensual sorting results due to the limited knowledge, experience, and ability of a single expert. The algorithms take into account the boundary profiles of various experts and employ a minimum adjustment optimization model to obtain consensual boundary profiles. The TOPSIS-Sort-B method allows for the individual and group sorting of alternatives based on individual and group decision matrices [30]. Furthermore, a variety of local modification strategy-based feedback configurations are suggested in order to assist experts in modifying their evaluations. In addition, experts' grouping is frequently based on shared preferences and disregards individual opinions where knowledge elicitation is critical [31]. The conventional framework for generating collective opinions may therefore produce unreliable decision results. To address this issue, the authors propose a two-tiered framework for generating collective opinions that are expert-structured and risk-appetite-integrated [31]. In a recent study [32], a minimum adjustment-based consensus algorithm was proposed in order to address the challenges of achieving consensus in multi-criteria GDM problems with multi-granular unbalanced linguistic information. The authors of that study acknowledged the significance of social networks in real-world GDM scenarios and suggested that there was a need for consensus reaching models that consider the impact of social networks. Specifically, they argued that consensus-reaching models for multi-criteria GDM problems with multi-granular unbalanced linguistic information in social network environments require further investigation [32]. Moreover, given the current dearth of appropriate techniques for representing group perception, the novel linguistic approximation tools [33] are therefore crucial for computing with words (CWW).

Finally, after careful consideration of the researched literature, Tables 1–3 present the most commonly used criteria for the selection of distribution center locations, which have been categorized into different aspects. This research focuses on investment, connectivity, and environmental aspects, which were identified to be dominant throughout the reviewed literature.

Table 1. Investment aspect: Criteria for selection of distribution center location.

Main Criteria	Sub Criteria	Description	Authors	Criteria Type
Investment aspect (C1)	Land Cost (C11)	The price of the plot where the distribution center will be located.	[4,9,18–21,25–28]	Cost
	Accessibility (C12)	Plot's existing accessibility.	[4,19,20]	Benefit
	Logistics Cost (C13)	Logistics costs such as building costs, inventory-carrying costs, administrative costs and/or depreciation costs.	[4,19–21,25,26,34]	Cost
	Possibility of expansion (C14)	Plot's size allows expansion of the distribution center.	[4,19,26–28]	Benefit
	Security (C15)	Security of the location from accidents, vandalism, theft, etc.	[4,19,23,26]	Benefit

Table 2. Connectivity aspect: Criteria for selection of distribution center location.

Main Criteria	Sub Criteria	Description	Authors	Criteria Type
Connectivity aspect (C2)	Connectivity to multimodal transport (C21)	Availability of multimodal transport in the plot's surroundings.	[4,19,23,25,26,28]	Benefit
	Transportation Time (C22)	Transportation time from the plot to the demand point.	[18,19,21]	Cost
	Proximity to Airport (C23)	The plot's proximity to the airport.	[10,18,22,23,26,34]	Cost
	Proximity to Highway (C24)	The plot's proximity to the highway.	[9,17,21,22,25,34]	Cost
	Proximity to Railway (C25)	The plot's proximity to the railway.	[9,17,21,22,25,28]	Cost
	Distance to Markets/Customers (C26)	Distance between the plot and the markets or customers.	[4,7,18,19,21,22,25,26,28,35]	Cost
	Distance to Manufacturers/Suppliers (C27)	Distance between the plot and the manufacturers or suppliers.	[4,17–19,21,25,26,35]	Cost

Table 3. Environmental aspect: Criteria for selection of distribution center location.

Main Criteria	Sub Criteria	Description	Authors	Criteria Type
Environmental aspect (C3)	Environmental impact (C31)	Impact of the implementation of the distribution center on the environment.	[4,15,16,19,26,36–38]	Cost
	Distance to forest area (C32)	Plot's distance from the forest area.	[21,24,33]	Benefit
	Distance to water resources (C33)	Plot's distance from the ground and underground water resources.	[15,16,21,33,36]	Benefit

3. Methodology and Methods

In recent years, the Brčko District of BiH has made significant infrastructure investments in order to attract both domestic and foreign investment. Our research was conducted in collaboration with the local government and the Department of Economic Development, Sports, and Culture in order to identify the most suitable business zone for the establishment of distribution centers for various companies operating in Brčko. To accomplish this, a panel of five experts was assembled to conduct the research. The research was carried out in five phases:

- Phase 1: Selection of research criteria and alternatives.
- Phase 2: Formation of the survey questionnaire and data collection.
- Phase 3: Processing the collected data and calculating the weight of the criteria
- Phase 4: Ranking of locations for distribution centers.
- Phase 5: Validation of results and conducting sensitivity analysis.

Phase 1 of this research aimed to identify the research criteria and alternatives. Three aspects were considered when determining the criteria for this research: investment, connectivity, and environmental aspects, all of which were further subdivided into individual sub-criteria, as demonstrated in Tables 1–3. Following expert consultation, six business zones were selected as alternatives. These included:

- McGowern Base (L1), which covers 170 ha and is located in the south of Brčko District.
- Brka Brdo Šterac (L2), which covers 35.9 ha and is located in the southwest of the Brčko District.
- Pirometal—Interplet (L3), which covers 36 ha and is located in the east of the Brčko District
- Bodarište (L4), which covers 20.8 ha and is located in the east of Brčko District.
- Donji Rahić—Ulović (L5), which extends over 88 ha and is located in the west of Brčko District.
- Gredice—Gaj (L6), which extends over 44 ha and is located in the southeast of Brčko District.

Following the identification of criteria and alternatives, Phase 2 of this research involved developing a survey questionnaire. The survey questionnaire was divided into two sections. The first section aimed to determine the importance of specific criteria for the experts. They needed to rank the criteria in order of importance and then evaluate them using linguistic evaluations, as demonstrated in Table 4. The second section of the survey questionnaire assessed the alternatives using linguistic values ranging from very high to very low (Table 4). The experts rated each chosen alternative on a seven-point scale.

Table 4. Linguistic values and belonging to fuzzy numbers.

Linguistic Variable for Criteria	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
equal significant	ES	0	0	0
Linguistic variable for Alternative	**Abbreviation**	**Fuzzy Numbers**		
Very low	VL	1	1	2
Low	L	1	2	4
Medium low	ML	2	4	6
Medium	M	3	5	7
Medium high	MH	5	7	9
High	H	7	9	10
Very high	VH	9	10	10

In Phase 3 of this research, the collected data was first processed, and the information from the first section of the survey was used to determine weights using the IMF SWARA method. Additionally, the information from the second section of the survey was used to rank the observed alternatives using the fuzzy CRADIS method. These methods will be explained in the following paragraphs.

The IMF SWARA method is a variant of the fuzzy SWARA method [39,40], which follows the same steps but uses a different value scale (Table 4). The steps involved in this method are as follows:

Step 1: Identification and selection of criteria.

Step 2: Sorting the criteria in order of importance from the most important to the least important.

Step 3: Calculating the relative importance of criteria, with the most important criterion assigned the value zero (0), and the other criteria ordered by importance. The value of s_j is then determined based on its relation to the previously more important criterion. This value is the ratio of that criterion to the previously better criterion, as shown in Table 4. In this manner, the value of s_j is calculated for all criteria.

Step 4: The coefficient k_j, is calculated based on the expression:

$$k_j = \begin{cases} 1 \ \ if\ j = 1 \\ s_j + 1 \ \ if\ j > 1 \end{cases} \tag{1}$$

Step 5: The significance value q_j, is calculated based on the expression:

$$q_j = \begin{cases} 1 \ \ if\ j = 1 \\ \frac{q_j - 1}{\bar{k}_j} \ \ if\ j > 1 \end{cases} \tag{2}$$

Step 6: The criteria weight w_j, is calculated based on the expression:

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

Phase 4 of our research involved ranking locations, which were achieved using the Fuzzy CRADIS method. The Fuzzy CRADIS method is a fuzzy set application in the CRADIS method developed by Puška et al. [41]. The steps involved are as follows [42]:

Step 1: Formation of the initial decision matrix.

Step 2: Normalization of the decision matrix.

For benefit criteria

$$n_{ij} = \frac{x_{ij}^l}{\max x_j^u}, \frac{x_{ij}^m}{\max x_j^u}, \frac{x_{ij}^u}{\max x_j^u} \tag{4}$$

For cost criteria

$$n_{ij} = \frac{\min x_{ij}^l}{x_{ij}^l}, \frac{\min x_{ij}^l}{x_{ij}^m}, \frac{\min x_{ij}^l}{x_{ij}^u} \tag{5}$$

When calculating the normalization for the benefit criteria, the highest value of the fuzzy number for the observed criterion is considered. The values of all alternatives for that criterion are then divided by this value. In contrast, when calculating normalization for the cost criterion, the smallest value of the fuzzy number is used. This value is then divided by the other data values for the observed alternatives and for all fuzzy numbers.

Step 3: Weighting of the decision matrix.

$$\tilde{v}_{ij} = \left(v_{ij}^l, v_{ij}^m, v_{ij}^u\right) = \tilde{n}_j \times \tilde{w}_j \tag{6}$$

Thus, v_{ij}^{l} is the first fuzzy number of the weighted decision matrix, v_{ij}^{m} is the second fuzzy number of the weighted decision matrix, and v_{ij}^{u} is the third fuzzy number of the weighted decision matrix.

Step 4: Determination of ideal and anti-ideal values.

$t_i = \max\widetilde{v}_{ij}$, where

$$\widetilde{v}_{ij} = \left(v_{ij}^{l}, v_{ij}^{m}, v_{ij}^{u}\right) \tag{7}$$

$t_{ai} = \min\widetilde{v}_{ij}$, where

$$\widetilde{v}_{ij} = \left(v_{ij}^{l}, v_{ij}^{m}, v_{ij}^{u}\right) \tag{8}$$

In this step, the ideal value (t_i) is established, which represents the maximum value in the weighted decision matrix, and the anti-ideal value (t_{ai}), which represents the minimum value in the weighted decision matrix, is also established.

Step 5: Calculation of distances from ideal and anti-ideal values.

$$d^{+} = t_i - \widetilde{v}_{ij} \tag{9}$$

$$d^{-} = \widetilde{v}_{ij} - t_{ai} \tag{10}$$

The distance between ideal and anti-ideal values is calculated by subtracting the data from the weighted decision matrix from the highest value (ideal value). The distance between each weighted decision matrix value and the smallest value (anti-ideal value) is then calculated. Positive values of the distance from the ideal value d^{+}, and the anti-ideal value d^{-} are obtained in this manner.

Step 6: Formation of ideal and anti-ideal optimal alternatives based on distances from the ideal and anti-ideal values.

The ideal optimal alternative s_0^{+} is the smallest value of the alternative for certain criteria (d^{+}), while the anti-ideal alternative s_0^{-} is the largest value of certain criteria (d^{-}). Each alternative aims to be as far from the anti-ideal value as possible while remaining as close to the ideal value as possible.

Step 7: Calculation of the sum of the deviations of individual alternatives from ideal and anti-ideal values.

$$s_i^{+} = \sum_{j=1}^{n} d^{+} \tag{11}$$

$$s_i^{-} = \sum_{j=1}^{n} d^{-} \tag{12}$$

In this step, the values of the alternatives are calculated based on the deviation from the ideal and anti-ideal values. This sum is also calculated for optimal alternatives.

Step 8: Defuzzification of alternative deviations from ideal and anti-ideal values.

$$s_{i\ def}^{\pm} = \frac{d_i^{l} + 4d_i^{m} + d_i^{u}}{6} \tag{13}$$

In this step, the fuzzy numbers are transformed into crisp numbers, where di represents the first, second and third fuzzy number of $s_i^{\pm}$.

Step 9: Calculation of the utility function for each alternative based on the deviations from the ideal alternatives.

$$K_i^{+} = \frac{s_0^{+}}{s_i^{+}} \tag{14}$$

$$K_i^{-} = \frac{s_i^{-}}{s_0^{-}} \tag{15}$$

Here, s_0^+ represents the ideal optimal alternative, while s_0^- represents the anti-ideal optimal alternative formed in step 6.

In this step, the value of the optimal ideal alternative (s_0^-) is divided by the value of the alternative (s_i^+) in the expression for K_i^+. With the expression for K_i^-, each alternative (s_i^-) is divided by the optimal anti-ideal alternative (s_0^-).

Step 10: Ranking of alternatives.

$$Q_i = \frac{K_i^+ + K_i^+}{2} \tag{16}$$

The Fuzzy CRADIS method determines the best and worst alternatives based on their respective values. The best alternative is the one with the highest value, while the worst alternative is the one with the lowest value according to the Fuzzy CRADIS method.

After determining the highest-ranked location for the distribution center, the fifth step of our research involved validating the obtained results and performing a sensitivity analysis. In addition to the fuzzy CRADIS method, six other fuzzy methods were used: fuzzy Multi-Attributive Border Approximation Area Comparison (MABAC), fuzzy Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS), fuzzy Weighted Aggregated Sum Product Assessment (WASPAS), fuzzy Simple Additive Weighting (SAW), fuzzy Additive Ratio Assessment (ARAS), and fuzzy TOPSIS. The primary objective of using these different methods was to determine the stability of the ranking order of alternatives [43] and whether the ranking orders obtained by other methods were related. This would confirm or refute the results obtained by the fuzzy CRADIS method. Subsequently, a sensitivity analysis was conducted in order to determine the influence of individual criteria on the ranking order [44]. This analysis enabled the study of how individual criteria affect the ranking of alternatives and provided recommendations for how to make each location more appealing, i.e., what actions the Government of the Brčko District of BiH could take in order to encourage local development.

4. Results

To evaluate the business zones and determine the most suitable location for distribution centers in the Brčko District, an expert assessment was employed. The initial task for the experts was to assess the importance of the criteria. In this regard, subjective evaluations from the experts were utilized, as they determined the level of importance for each criterion. The primary criteria for this research were the aspects of distribution centers, and each expert prioritized these three aspects or main criteria and assigned lower ratings to less significant criteria. Furthermore, weightings for the criteria were determined using the IMF SWARA method. Two experts prioritized the investment criterion over connectivity, two experts believed that both criteria had equal significance, and one expert believed that the connectivity criterion was more important. All experts agreed that the environmental aspect was the least significant in establishing distribution centers. This may be due to the proximity of these locations to residential areas, which would limit the impact on forests, waterways, and the environment.

The results obtained indicate that the investment criterion has the greatest importance, followed by connectivity; the environmental aspect was rated the least important (Table 5). These results were obtained by calculating the weightings for each expert separately, and the average value of all criteria was used to determine the aggregate value of the weightings. This approach assigned equal importance to all experts. The s_j value was formed based on the preferences of individual experts for each criterion. Decision makers (DMs) evaluated how much each criterion was worse than the previous better criterion. The first DM assessed that criterion C2 was less significant than C1, while C3 was equal in importance to C2. All main criteria were evaluated similarly. Weights for the main criteria were obtained by applying the IMF SWARA method, and these weights were determined individually for each DM. The average weight for the main criteria was then calculated. As a result, the main criterion C1 received the highest weight, followed by criterion C2. In the opinion of the DMs, criterion C3 was the least important.

Table 5. Weights of the main criteria.

DM1		s_j			k_j			q_j			w_j	
C1				1.00	1.00	1.00	1.00	1.00	1.00	0.38	0.39	0.40
C2	0.22	0.25	0.29	1.25	1.29	1.33	0.75	0.78	0.80	0.29	0.30	0.32
C3	0.00	0.00	0.00	1.00	1.00	1.00	0.75	0.78	0.80	0.29	0.30	0.32
						sum	2.50	2.56	2.60			
DM2		s_j			k_j			q_j			w_j	
C1				1.00	1.00	1.00	1.00	1.00	1.00	0.35	0.36	0.36
C2	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.35	0.36	0.36
C3	0.22	0.25	0.29	1.22	1.25	1.29	0.78	0.80	0.82	0.28	0.29	0.29
						sum	2.78	2.80	2.82			
DM3		s_j			k_j			q_j			w_j	
C1				1.00	1.00	1.00	1.00	1.00	1.00	0.36	0.36	0.36
C2	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.36	0.36	0.36
C3	0.25	0.29	0.33	1.22	1.25	1.29	0.78	0.80	0.82	0.27	0.28	0.29
						sum	2.78	2.80	2.82			
DM4		s_j			k_j			q_j			w_j	
C1				1.00	1.00	1.00	1.00	1.00	1.00	0.40	0.41	0.42
C2	0.22	0.25	0.29	1.00	1.00	1.00	1.00	1.00	1.00	0.31	0.33	0.34
C3	0.22	0.25	0.29	1.22	1.25	1.29	0.78	0.80	0.82	0.24	0.26	0.28
						sum	2.78	2.80	2.82			
DM5		s_j			k_j			q_j			w_j	
C2				1.00	1.00	1.00	1.00	1.00	1.00	0.40	0.41	0.42
C1	0.22	0.25	0.29	1.00	1.00	1.00	1.00	1.00	1.00	0.31	0.33	0.34
C3	0.22	0.25	0.29	1.22	1.25	1.29	0.78	0.80	0.82	0.24	0.26	0.28
						sum	2.78	2.80	2.82			
		C1			**C2**			**C3**				
DM1	0.38	0.39	0.4	0.29	0.3	0.32	0.29	0.3	0.32			
DM2	0.35	0.36	0.36	0.35	0.36	0.36	0.28	0.29	0.29			
DM3	0.35	0.36	0.36	0.35	0.36	0.36	0.28	0.29	0.29			
DM4	0.4	0.41	0.42	0.31	0.33	0.34	0.24	0.26	0.28			
DM5	0.31	0.33	0.34	0.4	0.41	0.42	0.24	0.26	0.28			
Average	0.36	0.37	0.38	0.34	0.35	0.36	0.27	0.28	0.29			

After determining the weights of the main criteria, the experts proceeded to determine the weights of the sub-criteria. The procedure was carried out in the same manner as for the main criteria, and the results are presented in Table 6. The results indicate that for the investment criterion, the sub-criterion C11—Land Cost—received the highest weight value, while the sub-criterion C15—Security—received the lowest weight value. Regarding the Connectivity criterion, the results indicate that the sub-criterion C21—Connectivity to Multimodal Transport—has the highest weight value, while the sub-criterion C23—Proximity to Airport—has the lowest weight value. Finally, for the ecological criterion, it can be seen that the sub-criterion C31—Environmental Impact—has the highest weight value, while the sub-criterion C32—Distance to Forest Area—has the lowest weight value.

Table 6. Weights of sub-criteria.

	C11			**C12**			**C13**			**C14**			**C15**								
DM1	0.27	0.28	0.29	0.16	0.18	0.19	0.21	0.22	0.24	0.16	0.18	0.19	0.12	0.14	0.16						
DM2	0.20	0.21	0.23	0.20	0.21	0.23	0.26	0.27	0.28	0.15	0.17	0.19	0.12	0.13	0.15						
DM3	0.24	0.24	0.24	0.18	0.19	0.20	0.24	0.24	0.24	0.18	0.19	0.20	0.14	0.15	0.16						
DM4	0.20	0.22	0.23	0.20	0.22	0.23	0.26	0.27	0.28	0.12	0.13	0.15	0.15	0.17	0.18						
DM5	0.26	0.27	0.28	0.20	0.22	0.23	0.20	0.22	0.23	0.12	0.14	0.15	0.16	0.17	0.18						
Avg.	0.23	0.24	0.25	0.19	0.20	0.21	0.23	0.24	0.25	0.15	0.16	0.18	0.14	0.15	0.17						
	C21			**C22**			**C23**			**C24**			**C25**			**C26**			**C27**		
DM1	0.19	0.20	0.20	0.15	0.16	0.17	0.06	0.08	0.09	0.11	0.12	0.13	0.08	0.10	0.11	0.19	0.20	0.20	0.15	0.16	0.17
DM2	0.20	0.20	0.21	0.15	0.16	0.17	0.06	0.07	0.09	0.15	0.16	0.17	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17
DM3	0.18	0.19	0.20	0.18	0.19	0.20	0.06	0.07	0.08	0.18	0.19	0.20	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16
DM4	0.18	0.18	0.19	0.14	0.15	0.15	0.07	0.08	0.09	0.14	0.15	0.15	0.10	0.11	0.12	0.14	0.15	0.15	0.18	0.18	0.19
DM5	0.20	0.20	0.21	0.15	0.16	0.17	0.06	0.07	0.09	0.15	0.16	0.17	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Avg.	0.19	0.20	0.20	0.16	0.16	0.17	0.06	0.07	0.09	0.15	0.16	0.17	0.09	0.10	0.11	0.14	0.15	0.15	0.16	0.16	0.17
	C31			**C32**			**C33**														
DM1	0.36	0.36	0.37	0.26	0.27	0.29	0.36	0.36	0.37												
DM2	0.41	0.42	0.43	0.23	0.25	0.27	0.32	0.33	0.35												
DM3	0.41	0.42	0.44	0.21	0.24	0.27	0.32	0.34	0.36												
DM4	0.36	0.37	0.38	0.24	0.26	0.28	0.36	0.37	0.38												
DM5	0.36	0.36	0.36	0.27	0.28	0.29	0.36	0.36	0.36												
Avg.	0.38	0.39	0.39	0.24	0.26	0.28	0.34	0.35	0.36												

To obtain the final weights for individual criteria, the weights of the main and sub-criteria were multiplied. However, as there were not an equal number of sub-criteria in each of the main criteria or aspects, the weights were adjusted. The weight of the environmental criterion was divided by seven (7) and multiplied by five (5) to align it with the investment aspect, while for the connectivity criterion, the weight was divided by three (3) and multiplied by five (5). This was because the investment criterion had five sub-criteria, the connectivity criterion had seven sub-criteria, and the environmental criterion had only three sub-criteria. Failure to align the weights would have resulted in the sub-criteria of the environmental aspect having the highest weights since it had the smallest number of sub-criteria, while the sub-criteria of the connectivity aspect would have had the lowest weights as it had the most sub-criteria.

After determining the criteria weights using the second part of the survey questionnaire, experts evaluated the selected locations. They evaluated how well each alternative fulfilled the sub-criteria concerning the selected alternatives (Table 7).

After evaluating the alternatives for the sub-criteria using linguistic values, the next step was to carry out the steps of the fuzzy CRADIS method. The first step of the method involves forming the initial decision matrix. Based on expert assessments, a linguistic decision matrix is formed (Table 7). To rank these alternatives, it is necessary to transform the linguistic values into corresponding fuzzy numbers. This is achieved by applying the membership function (Table 4). In this way, a fuzzy initial decision matrix is formed, which serves as the basis for conducting the fuzzy CRADIS method. The second step of the fuzzy CRADIS method is to normalize the data of the fuzzy decision matrix. Different types of normalization are applied depending on the type of criterion; that is, if the criterion is a benefit, normalization is carried out for benefit criteria (expression 4), and if it is a cost criterion, normalization is carried out for cost criteria (expression 5).

Table 7. Linguistic evaluations of research alternatives.

DM1	**C11**	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C31**	**C32**	**C33**
L1	M	H	ML	H	MH	MH	L	MH	ML	L	ML	L	ML	M	M
L2	ML	MH	L	M	MH	MH	ML	M	ML	ML	M	ML	ML	M	ML
L3	MH	MH	M	M	M	H	L	ML	M	ML	M	ML	M	M	ML
L4	VL	M	M	L	M	M	M	ML	M	M	MH	M	M	ML	M
L5	L	MH	L	MH	MH	M	L	ML	ML	M	M	ML	M	ML	ML
L6	L	MH	ML	M	H	MH	ML	ML	M	M	ML	L	ML	M	M
DM2	**C11**	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C31**	**C32**	**C33**
L1	ML	VH	ML	VH	MH	M	ML	M	M	ML	L	ML	L	MH	M
L2	L	H	M	MH	MH	M	M	M	M	M	ML	M	L	MH	M
L3	MH	MH	ML	MH	MH	MH	ML	M	MH	M	ML	M	ML	M	ML
L4	L	MH	M	M	M	M	M	ML	MH	MH	M	MH	ML	M	M
L5	L	H	ML	H	MH	ML	ML	M	M	MH	ML	M	ML	M	ML
L6	L	MH	M	H	MH	M	ML	M	M	MH	ML	M	ML	MH	M
DM3	**C11**	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C31**	**C32**	**C33**
L1	M	H	L	H	MH	MH	L	M	M	ML	L	ML	ML	M	M
L2	L	H	ML	MH	MH	M	ML	M	M	M	ML	M	M	M	M
L3	MH	MH	ML	MH	MH	MH	L	M	MH	M	L	ML	M	M	M
L4	VL	M	ML	M	MH	MH	M	ML	M	M	ML	M	ML	ML	ML
L5	VL	MH	L	H	MH	M	ML	M	M	M	ML	M	ML	ML	ML
L6	VL	H	ML	MH	H	M	ML	M	M	M	ML	M	M	ML	M
DM4	**C11**	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C31**	**C32**	**C33**
L1	MH	MH	M	MH	M	MH	ML	M	ML	M	ML	L	M	MH	M
L2	ML	MH	M	ML	M	MH	M	M	ML	M	ML	L	M	MH	M
L3	H	MH	M	ML	M	MH	ML	M	ML	M	ML	L	M	MH	M
L4	L	ML	MH	L	M	M	M	M	M	MH	M	ML	M	M	ML
L5	ML	MH	M	M	M	M	ML	ML	ML	M	M	ML	M	M	ML
L6	ML	MH	M	ML	M	MH	M	M	M	MH	ML	L	M	M	M
DM5	**C11**	**C12**	**C13**	**C14**	**C15**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C31**	**C32**	**C33**
L1	M	VH	ML	H	MH	M	L	MH	ML	L	ML	L	ML	M	ML
L2	L	H	M	ML	M	M	ML	M	M	ML	M	ML	M	M	M
L3	MH	H	ML	ML	MH	MH	L	M	M	ML	L	L	M	M	M
L4	VL	MH	MH	L	MH	ML	ML	M	ML	M	M	ML	M	M	ML
L5	L	H	ML	MH	MH	M	L	ML	M	ML	M	ML	ML	M	M
L6	L	VH	M	M	MH	M	ML	ML	M	M	ML	L	M	M	M

The third step of the fuzzy CRADIS method is to weigh the normalized decision matrix. This is performed by multiplying the data from the normalized decision matrix with the corresponding weights obtained by the IMF SWARA method (expression 6). The fourth step of the fuzzy CRADIS method is to determine the ideal and anti-ideal values. The ideal value is the one with the highest score in the weighted normalized decision matrix (expression 7), while the anti-ideal value is the one with the lowest score (expression 8). The fifth step involves reducing the values in the weighted normalized decision matrix by the ideal and anti-ideal values (expressions 9 and 10). The sixth step is to determine the optimal (S_0) alternative. Optimal alternatives are those that are least distant from the ideal values or farthest from the anti-ideal values. The seventh step of the fuzzy CRADIS method involves adding up the values of alternatives for the corresponding fuzzy numbers (Table 8) (expressions 11 and 12). The eighth step is to defuzzify values (expression 13). Then, in the ninth step, utility functions are calculated (expressions 14 and 15), and in the tenth step, an alternative ranking order is formed (expression 16). The results obtained using the fuzzy CRADIS method showed that the best-ranked location was McGowern Base (L1), while the worst ranked alternative was Bodarište (L4). Based on these results, McGowern Base represents the best location for companies in the Brčko District of BiH to establish their distribution centers.

Table 8. Values of the fuzzy CRADIS method.

	s^+	s^-	$Def\ s^+$	$Def\ s^-$	K_i^+	K_i^-	Q_i	RANK
L1	(0.56 0.39 0.57)	(0.63 0.45 0.49)	0.447	0.488	0.840	0.872	0.856	1
L2	(0.69 0.47 0.61)	(0.50 0.38 0.44)	0.528	0.408	0.712	0.729	0.721	4
L3	(0.69 0.47 0.61)	(0.50 0.38 0.44)	0.529	0.407	0.711	0.727	0.719	5
L4	(0.79 0.52 0.67)	(0.40 0.32 0.39)	0.590	0.346	0.637	0.618	0.628	6
L5	(0.65 0.45 0.62)	(0.54 0.39 0.44)	0.512	0.423	0.734	0.756	0.745	2
L6	(0.67 0.45 0.61)	(0.52 0.39 0.45)	0.513	0.423	0.733	0.756	0.745	3
S_0	(0.46 0.32 0.53)	(0.73 0.53 0.53)	0.376	0.560				

After the ranking of alternatives and the selection of the best location for establishing the distribution center, the research results were validated. The validation utilized the same fuzzy decision matrix and criteria weights, but a different rank order was formed based on other fuzzy methods. The results obtained using fuzzy MABAC and fuzzy TOPSIS methods demonstrated a difference in the rank order of alternatives L5 and L6 (Figure 1). The reason for this discrepancy could be found in the values obtained by the fuzzy CRADIS method, as the values of alternatives L5 and L6 differed only in the fourth decimal place. This slight difference in values could have affected the ranking order in the fuzzy TOPSIS and fuzzy MABAC methods. Additionally, fuzzy MABAC employs a different normalization technique, which could have contributed to the different ranking order. Based on the validation results, it can be concluded that the rank order obtained using the fuzzy CRADIS method is valid and can be used for a sensitivity analysis.

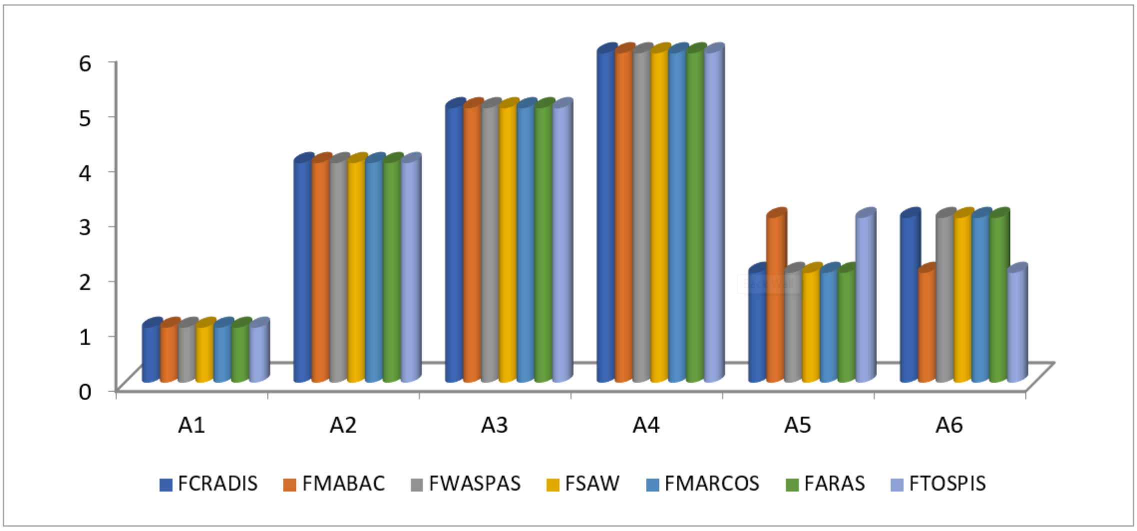

Figure 1. Validation of the results.

The purpose of a sensitivity analysis is to determine the contribution of individual criteria to the ranking order of alternatives. Prior to conducting a sensitivity analysis, scenarios are developed upon which the analysis is based. In this study, scenarios were determined as follows: for each criterion, its weight was reduced by 30%, 60%, and 90%, and the impact of this reduction on the ranking order of alternatives was determined. Since there were 15 sub-criteria, and each was reduced three times, 45 scenarios were formed. The results of the analysis (Figure 2) consistently demonstrated that location L1 occupied the top rank in all scenarios, while L4 occupied the lowest rank (Figure 2). Locations L5 and L6 changed their ranking order depending on the scenario, thus confirming the differences observed during validation. This is because these two locations were evaluated similarly, so any change in the weights of individual criteria resulted in a change in the ranking of these two locations. Based on the ranking order, it can be concluded that location L6 occupied the second rank in several scenarios compared to location L5. Therefore, it can be stated that the second location suitable for distribution centers is L6, followed by L5. In several scenarios, location L3 occupied the fourth rank compared to A2. However, in one scenario, location L3 occupied the second rank, specifically, when the weight of the Accessibility criterion (C12) was reduced by 90%. Therefore, to achieve a higher rank for this alternative, accessibility needs to be improved, i.e., the government of Brčko District needs to provide better access to this location. Based on this analysis, it is possible to determine which location is highly sensitive to changes in the weights of the criteria. For instance, to outperform location L2, location L3 needs to improve criteria C1, C2, and C9. This is because when the weight of these criteria was reduced, location L3 was ranked higher, and indicating that location L2 had better indicators for these criteria compared to location L3. Therefore, it is necessary to perform a comparison of locations and identify areas that need improvement in order to make them more attractive for the establishment of distribution centers.

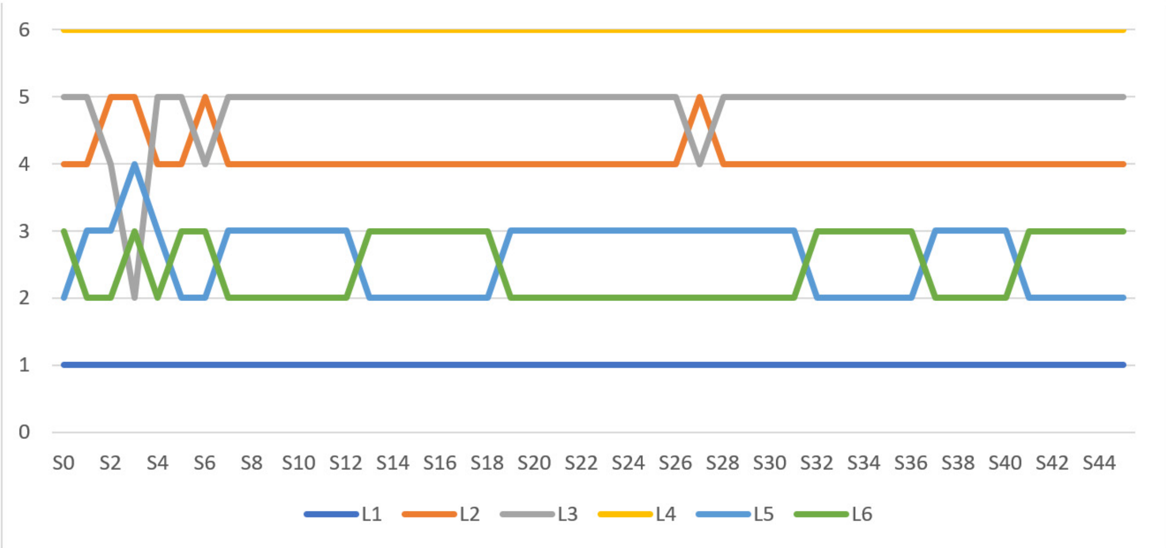

Figure 2. Sensitivity analysis.

5. Discussion

The Government of Brčko District of BiH has taken certain measures to establish industrial zones that can serve as potential sites for various distribution centers to attract investors. Numerous factors, including investment, connectivity, and environmental aspects [26], influence the selection of a location for distribution centers, and these three aspects were used in the research presented in this paper. Employees of the Department of Economic Development, Sport, and Culture were engaged in this research, since they are partially involved in the formation of industrial zones and the development of entrepreneurship in Brčko District of BiH. Given that these employees have been actively working on the formation of these zones since 2010, they are well versed in all the potential locations for establishing distribution centers. Therefore, their opinions and evaluations were used in this research in order to evaluate the potential distribution center locations.

Initially, the experts determined the criteria by which the selected locations and potential locations for establishing distribution centers would be evaluated. The experts were provided with all the Department's documents, which helped them choose six potential locations and then assess the criteria and alternatives. Since it is sometimes difficult to determine the numerical rating for a particular alternative, linguistic assessments were used [45] in order to make the research more closely resemble human thinking. Therefore, fuzzy sets were used in this study, along with the IMF SWARA and fuzzy CRADIS methods. Fuzzy sets transform linguistic values into fuzzy numbers, which can then be utilized with fuzzy MCDM methods.

To identify potential locations for the distribution center, experts evaluated the criteria used in this research. Three main aspects, or criteria, were used, each of which was further divided into sub-criteria. The connectivity aspect had the highest number of sub-criteria, while the ecological aspect had the lowest. The experts individually evaluated the main criteria, determining which criteria were more significant and which were less significant, using linguistic ratings. The results revealed that the experts considered investment aspects to be the most significant, followed by connectivity aspects, while ecological aspects were considered the least important. This was because the industrial zones being considered were located in suburban areas and were not near forest areas or water sources. Therefore, ecological criteria were not as important to the experts as investment or connectivity aspects.

Subsequently, the experts evaluated each individual criterion within the main criteria. Logistics costs were perceived as the most important in terms of the investment aspect. This is because any company that plans to build its own distribution center must aim for easy access to customers and suppliers [4]. It is, therefore, necessary to have good connectivity between these locations and the transportation network in order to reduce logistics costs. Following this sub-criterion, the price per square meter carries the most weight among these locations. This price actually raises the cost of investment [29]. For this investment aspect, the safety sub-criterion carries the least weight due to the fact that all of these locations are in close proximity to settlements, and hence have good safety.

In terms of connectivity, the experts determined that connectivity with multimodal transportation was the most important supporting criterion. It is essential for a location to be as close as possible to various modes of transportation in order to allow for the simultaneous delivery of goods to customers and the delivery of goods from suppliers using various modes of transportation. Thus, connectivity is critical when deciding where to establish a distribution center. Furthermore, to deliver products from suppliers as quickly as possible and to simultaneously ship them to customers, it is essential for each company to be located close to both suppliers and customers. As a result, the experts assigned significant weight to these sub-criteria. The sub-criterion of proximity to the airport was given the least weight, since air transport of goods is least used in BiH. Additionally, due to a number of restrictions, the use of railway services is declining in BiH [46]. Consequently, road transportation has taken the main role in the transportation of goods.

According to the experts' evaluation of the environmental aspect, the most important sub-criterion is the impact on the environment, followed by the distance from water resources and the distance from forest areas. This is due to the need to ensure that all industrial zones, which are potential locations for distribution centers, have a minimal environmental impact. To reduce the negative environmental impact of these locations, environmental protection measures must be implemented [47].

After obtaining the weights of the criteria, the weights of the sub-criteria were harmonized because there was not an equal number of sub-criteria for each main criterion. This harmonization is necessary since the sub-criteria in the environmental aspect were given twice the weight of the sub-criteria in the connectivity aspect. In this way, equal importance was given to all supporting criteria, so that there would be no deviations between individual criteria based on their affiliation with the main criteria.

Experts evaluated potential locations in the Brčko District in order to identify the most suitable location for establishing distribution centers. However, it should be noted that having a high price and high location security are not the same thing, despite the use of the same linguistic scale. Therefore, individual criteria were divided into two categories: benefit criteria and cost criteria. A higher rating is preferred for benefit criteria, while a lower rating is preferred for cost criteria. Every investor desired greater security while paying less for a specific piece of land or greater connectivity through multi-modal transportation while being closer to suppliers and customers. In the second step of the fuzzy CRADIS method, different normalizations were used depending on the type of criteria.

The results of the alternative ranking revealed that the industrial zone of McGowern Base has the best indicators overall, due to its high ratings for each of the specific criteria. However, a sensitivity analysis has shown that other locations may also be considered as distribution centers if their potential is recognized. Validation of the results and sensitivity analysis confirmed these findings and, furthermore, revealed that the location of Gredice-Gaj has better indicators than the location of Donji Rahić-Ulović, which was not initially reflected in the ranking. Therefore, additional analysis is necessary to obtain all the necessary information for decision-making.

The obtained ranking reflects the current situation in the Brčko District of BiH. However, the construction of two branches of a highway that will run through the district is currently underway. The situation on the ground is changing, which may have an impact on the final decision regarding the selection of a distribution center location. Thus, it is necessary to re-evaluate these and other locations once the routes of these highways are established. To make the Brčko District of BiH more appealing to investors, sustainable territorial development [48] should be implemented.

Future research could be directed towards solving the problem of location selection by ranking the criteria from most desirable to least desirable. This approach is called the multi-criteria group-sorting problem [49]. Moreover, when deciding on a location, different approaches and their consensus could be used [30].

6. Conclusions

The aim of the research presented in this paper was to assess and select suitable industrial zone locations for the establishment of distribution centers in the Brčko District of BiH. The research was conducted in collaboration with the Brčko District Government and the Department of Economic Development, Sports, and Culture. The department appointed experts to assess proposed locations using linguistic values combined with fuzzy sets. The experts began by identifying criteria and sub-criteria, as well as potential locations. The weights of these criteria, sub-criteria, and alternatives were then assessed using the IMF SWARA method, while the fuzzy CRADIS method was employed to determine the ranking order of alternatives.

According to the results of this research, the best location for establishing distribution centers in the Brčko District is the McGowern Base. This location also demonstrated the best indicators in the sensitivity analysis that was conducted. The sensitivity analysis, however, revealed that the Gredice-Gaj location is the second-best location for establishing distribution centers, despite the fact that it was not initially identified as such in the analysis. Consequently, the sensitivity analysis established the extent to which each location is sensitive to changes in the weights of individual criteria. The analysis revealed that the Donji Rahić-Ulović location is more sensitive to changes in the weights of the sub-criteria and serves as the third choice for establishing distribution centers.

The research presented in this paper has limitations in terms of the number of alternatives considered, as one of the potential locations not included in this research may provide better indicators. However, the experts selected the locations based on their judgment, and additional locations should be considered in future research. Another limitation of this study is related to the fuzzy methods employed. The fuzzy CRADIS method did not show a significant deviation from other fuzzy methods, as evidenced by the validation results. Therefore, the observed deviation between locations L5 and L6 can be considered insignificant.

Future research should consider additional criteria and alternatives, with a focus on individual industry branches, to provide investors with a more detailed assessment of all potential locations. The government of BiH's Brčko District should support such research. Moreover, since road traffic dominates in BiH, new motorway routes should be included in future studies.

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