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Optimizing Logistics Center Location in Brčko District: A Fuzzy Approach Analysis

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Abstract: In urban logistics, the strategic placement of logistics centers significantly influences cost efficiency. This study explores optimal locations for establishing logistics centers within the Brčko District of Bosnia and Herzegovina. The methodology involves expert evaluations, employing linguistic values to assess criteria and alternatives. A fuzzy approach is utilized to translate these values into actionable data. The application of the fuzzy Logarithm Methodology of Additive Weights (LMAW) method was instrumental in ascertaining the significance of various location selection criteria. Amongst these, connectivity to multinodular transport emerged as paramount. Concurrently, the fuzzy Combined Compromise Solution (CoCoSo) method facilitated the ranking of potential sites, identifying the Brka-Gajine Zone as the most favorable. These findings were substantiated through a comparative and sensitivity analysis. Comparative analysis reinforced the CoCoSo method's alignment with results derived from the fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. Sensitivity analysis revealed fluctuations in the rankings of locations A2 and A5 across twelve scenarios. This research not only demonstrates the efficacy of fuzzy methodologies in urban logistics center location selection but also highlights the Brka-Gajine Zone's potential as a burgeoning business hub, poised to become a dominant force in logistics. The study's findings offer valuable insights for urban planning and logistics optimization, emphasizing the role of multidimensional assessment in such decision-making processes.

Keywords: Urban logistics optimization; Fuzzy logic analysis; Multinodular transport connectivity; Logistics center site selection; Brčko district logistics planning

1 Introduction

In the contemporary global business landscape, the efficiency of logistics emerges as a pivotal factor for organizational success. The competitive edge of companies is increasingly being shaped by their logistical capabilities. Central to this is the role of logistics centers, which are instrumental in optimizing supply chains [1]. The efficacy of these centers hinges significantly on their location, particularly in urban logistics contexts. Within a logistics network, the strategic choice of location is fundamental for effective management of operations [2]. Optimal location selection not only reduces operational costs but also minimizes delivery times to other businesses or end consumers [3]. Hence, in urban logistics, the decision-making process for establishing a logistics center necessitates a comprehensive consideration of multiple factors [4]. The importance of location selection is accentuated by the need to balance proximity to major transport routes for swift supplier delivery and accessibility to urban centers for expedited customer service [5, 6].

This research focuses on the decision-making process concerning the siting of logistics centers in urban environments, emphasizing the use of fuzzy logic [7]. Fuzzy logic, a methodology adept at handling uncertainty and imprecision in data, offers a robust framework for decision-making in logistics [8]. The study aims to explore the efficacy of the fuzzy approach in selecting logistics center locations, with a case study centered on the Brčko District of Bosnia and Herzegovina. By integrating theoretical aspects of fuzzy logic with practical considerations such as infrastructural features, geographic connectivity, transportation costs, and market demands, this study seeks to elucidate the role of this approach in determining optimal locations for logistics centers.

This research endeavors to employ fuzzy logic for the analysis of variables, aiming to develop a model that encapsulates the complex interplay of diverse factors influencing the siting of logistics centers in urban environments. The goal is to furnish companies with a more nuanced understanding of the decision-making process in this context. The study's contribution lies in enhancing strategies for selecting locations of logistics centers, thereby fostering operational efficiency and competitive prowess in the global market. In this pursuit, the research utilizes specific fuzzy methods: the LMAW method for assessing the importance of various criteria, and the CoCoSo method for ranking potential locations suited to the needs of urban logistics centers.

The Brčko District, a unique administrative entity, presents a considerable opportunity for the development of logistics centers. This potential is set to be augmented with the future construction of two highways, facilitating connections between the eastern and western, as well as the northern and southern regions of Bosnia and Herzegovina. This development positions Brčko as a strategic hub. Additionally, Brčko's distinction as the only location in Bosnia and Herzegovina with a river port, coupled with its rail connectivity to the Republic of Croatia, further underscores its logistical significance. The significance of this research lies in its exploration of fuzzy logic application for logistics center location selection in the context of Brčko District's urban logistics. Moreover, it offers insights into new potential sites for logistics in the form of business zones within the Brčko District. Consequently, this study provides vital information for the establishment of logistics centers in the Brčko District, leveraging the district's forthcoming infrastructural advantages.

2 Literature Review

This section critically reviews existing literature, first examining the application of urban logistics in logistics centers, followed by an exploration of the application of fuzzy logic and multi-criteria decision-making methods in selecting logistics center locations.

2.1 Logistics Centers in Urban Logistics

The significance of logistics centers within the realm of urban logistics has been extensively studied. Rao et al. [9] highlight that logistics centers are integral to the urban logistics framework, playing a crucial role in the efficacy of a company's supply chain. Wang et al. [10] focus on sustainable urban logistics, noting the pivotal role of location selection in reducing transportation costs, delivery times, and carbon dioxide emissions. Rikalović et al. [11] utilized Geographic Information System (GIS) and SWOT analysis to select a logistics center location in the urban area of Apatin municipality, Serbia.

Özmen and Aydoğan [12] underscore the importance of proximity to urban centers in logistics center location selection, emphasizing cost reduction. Zhou et al. [13] explored agricultural product distribution in urban areas, proposing green logistics center layouts. Önden and Eldemir [14] identified optimal logistics center locations to minimize transportation costs, using expert opinions and mathematical modeling. Dyczkowska and Reshetnikova [15] analyzed logistics centers in Ukraine, with a special focus on those in the city of Lviv. Pamučar et al. [16] investigated transport route optimization between urban logistics centers to reduce environmental impact and harmful gas emissions.

Morganti and Gonzalez-Feliu [17] analyzed food delivery from logistics centers, using the Food Hub concept to enhance urban logistics. Yang and Sheng [18] examined the selection of logistics centers for urban vegetable supply in China. He et al. [19] optimized logistics and distribution centers using integer programming. Uyanik et al. [20] reviewed research on logistics center location selection, highlighting its criticality in urban logistics decision-making.

Collectively, these studies underscore the paramount importance of logistics center formation in urban areas, emphasizing the need for meticulous planning and decision-making in urban logistics.

2.2 Application of Fuzzy Logic in the Selection of Logistics Centers

The challenge of selecting optimal locations for logistics centers has been a focal point of numerous studies, with a particular emphasis on multi-criteria decision-making methods. For example, Rao et al. [9] applied fuzzy multi-attribute group decision-making, incorporating the TOPSIS and 2-tuple hybrid ordered weighted averaging (THOWA) operator. Özmen and Aydoğan [12] utilized the evaluation based on distance from average solution (EDAS) and best-worst method (BWM) for logistics center location selection. Ulutaş et al. [21] adopted fuzzy Stepwise Weight Assessment Ratio Analysis (SWARA) and CoCoSo methods for similar purposes. Pham et al. [22] employed a hybrid TOPSIS methodology for logistics center selection in Vietnam.

In Spain, Yazdani et al. [23] integrated rough set theory, data envelopment analysis (DEA), full consistency method (FUCOM), and CoCoSo to identify suitable logistics center locations. Önden et al. [24] combined GIS and fuzzy Analytic Hierarchy Process (AHP) for their research. Peker et al. [25] focused on a logistics center in Trabzon, highlighting the strategic importance of location and using the Analytic Network Process (ANP) method. Yu et al. [26] applied the AHP method, creating a two-level evaluation matrix for logistics center location selection. Liao et al. [27] utilized the CoCoSo method in a Pythagorean fuzzy environment for their study.

Uyanik et al. [28] adopted the Intuitionistic Fuzzy set combined with the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and TOPSIS methods for a logistics center in Istanbul. Yavas and Ozkan-Ozen [29] used fuzzy DEMATEL in the context of new industrial era logistics centers. Similarly, Nila and Roy [30] applied DEMATEL in a study focused on logistics centers 4.0. Kieu et al. [31] employed Spherical Fuzzy sets with AHP and CoCoSo for location selection in an agricultural supply chain.

Collectively, these studies illustrate the prevalent use of fuzzy set theory and multi-criteria decision-making methods in the process of selecting logistics center locations, reflecting their critical role in modern logistics management.

3 Methodology

When conducting the research, the steps (Figure 1) of the research methodology used were defined.

Figure 1. Research methodology

Note: This figure was prepared by the authors

The initial phase of this research involved defining the research problem. The central inquiry addresses the identification of the most suitable location for the establishment of a logistics center in the Brčko District of Bosnia and Herzegovina (BiH), targeting new enterprises seeking investment and business opportunities in this region. The Brčko District Government's commitment to fostering entrepreneurship through the development of business zones underscores the timeliness of this study. Consequently, this investigation was designed to assist in the selection of an optimal business zone for the development of logistics centers:

- A1 - Brka-Gajina zone, which extends to 71.0 ha and is connected to the regional road.
- A2 - The Donji Rahić-Ulović zone extends over 88.0 ha, and is located near the railway line.
- A3 - Zone Bukvik - south 1, which extends to 126.0 Ha, is connected to the regional road
- A4 - The Bodarište zone extends over 20.8 ha and is connected to the local road
- A5 - The Gredice-Kobilić zone is located on 36.5 ha and is connected to the local road
- A6 - Zone Krepšić extends over 11.5 ha and is connected to the local road

Following the determination of these alternatives, it became necessary to evaluate them against defined research criteria. The criteria for logistics center selection were derived from the prior research outlined in the literature review. Consequently, a set of ten criteria was established (refer to Table 1).

Following the identification of alternatives and criteria, an expert evaluation was conducted. A panel of ten experts, each possessing comprehensive knowledge of the Brčko District's geography and expertise in various domains such as traffic, entrepreneurship, and logistics, was assembled. This diverse group ensured a multifaceted examination of potential logistics center locations. For the evaluation process, both criteria and alternatives were assessed using a uniform linguistic scale, ranging from 'very bad' to 'very good' (refer to Table 2). This approach allowed the experts to evaluate each criterion consistently, without needing to adapt their assessments to the nature of individual criteria. The uniformity of this scale facilitated a straightforward evaluation process. To effectively utilize these linguistic values in determining the significance of the selected criteria and in evaluating the alternatives based on these criteria, a transformation into quantifiable measures was necessary. This was achieved by applying the fuzzy number membership function, which allowed for the translation of linguistic assessments into a format amenable to fuzzy logic analysis.

Table 1. Research criteria

Id	Criteria	Description
C1	Land costs	It includes the price of land in this business zone
C2	Convenience for expansion	The possibility of expanding the logistics center
C3	Connection with multinodular transport	Connection with different types of transport
C4	Availability of roads	The existence of various roads in the vicinity
C5	Possibility of access	Possibility of access by different vehicles
C6	Close to the urban center	Distance from the urban settlement
C7	Proximity to suppliers and customers	Distance between potential suppliers and customers
C8	Transportation time	Possibility of delivery in the shortest possible time
C9	Available communal infrastructure	Developed communal infrastructure (water, electricity, sewage)
C10	Impact on the environment	Possible impact on the environment of the distribution center

Table 2. Linguistic value scale with membership function

Linguistic Value	Membership Function
Very bad (VB)	(1, 1, 2)
Bad (B)	(2, 3, 4)
Medium (M)	(4, 5, 6)
Good (G)	(6, 7, 8)
Very good (VG)	(8, 9, 9)

Upon completion of the criteria evaluation by experts using linguistic values, the subsequent step involves calculating the weights of these criteria utilizing the LMAW method. Developed by Pamučar et al. [32], the LMAW method offers a distinct approach compared to other methods such as the FUCOM or the AHP. Unlike FUCOM, which requires initial ranking and evaluation of criteria, or AHP, which necessitates pairwise comparison of criteria, LMAW simplifies the process by directly determining the importance of criteria based on linguistic assessments of how 'bad' or 'good' each criterion is perceived. The procedural steps of the method are outlined as follows:

Step 1. Prioritization of criteria using linguistic value.

Step 2. Defining the absolute anti-ideal point ($\tilde{\gamma}_{AIP}$).

Step 3. Defining the fuzzy vector.

$$\tilde{\mu}^e_{Cn} = \left(\frac{\tilde{\gamma}^e_{Cn}}{\tilde{\gamma}_{AIP}}\right) = \left(\frac{\gamma^{(l)e}_{Cn}}{\gamma^{(n)}_{AIP}}, \frac{\gamma^{(m)e}_{Cn}}{\gamma^{(m)}_{AIP}}, \frac{\gamma^{(n)e}_{Cn}}{\gamma^{(l)}_{AIP}}\right) \tag{1}$$

Step 4. Determination of the vector of weight coefficients.

$$\widetilde{\omega}^e_j = \left(\frac{\ln\left(\tilde{\mu}^e_{Cn}\right)}{\ln\left(\prod_{j=1}^n \tilde{\mu}^e_{Cn}\right)}\right) = \left(\frac{\ln\left(\tilde{\mu}^{(l)e}_{Cn}\right)}{\ln\left(\prod_{j=1}^n \tilde{\mu}^{(n)e}_{Cn}\right)}, \frac{\ln\left(\tilde{\mu}^{(m)e}_{Cn}\right)}{\ln\left(\prod_{j=1}^n \tilde{\mu}^{(m)e}_{Cn}\right)}, \frac{\ln\left(\tilde{\mu}^{(n)e}_{Cn}\right)}{\ln\left(\prod_{j=1}^n \tilde{\mu}^{(l)e}_{Cn}\right)}\right) \tag{2}$$

Step 5. Calculation of final values of criteria weights.

Upon establishing the criteria weights, the next phase involved evaluating the alternatives against these criteria. This evaluation is pivotal for ascertaining the most appropriate location for new logistics centers. In the realm of multi-criteria analysis, various methods exist, each with its own merits and limitations. The selection of a specific method typically resides with the researcher. For this study, the CoCoSo method, developed by Yazdani et al. [33], was employed. This method has been previously utilized in research concerning logistics center location selection [21, 27, 31]. The steps of this method are:

Step 1. Formation of the initial decision matrix.

Step 2. Transformation of linguistic values into fuzzy numbers.

Step 3. Normalization of the fuzzy decision matrix.

$$\tilde{r}_{ij} = \left(\frac{\alpha_{ij}^{l} - \alpha_{i\min}^{l}}{\alpha_{i\max}^{n} - \alpha_{i\min}^{l}}; \frac{\alpha_{ij}^{m} - \alpha_{i\min}^{l}}{\alpha_{i\max}^{n} - \alpha_{i\min}^{l}}; \frac{\alpha_{ij}^{n} - \alpha_{i\min}^{l}}{\alpha_{i\max}^{n} - \alpha_{i\min}^{l}} \right) \tag{3}$$

where, $\alpha_{i\max}^{n}$ represents the maximum value of the third fuzzy number, $\alpha_{i\min}^{l}$ represents the minimum value of the first fuzzy number for a certain criterion.

Step 4. Determining the values S_i and P_i .

$$\tilde{S}_i = \sum_{j=1}^{n} (\tilde{r}_{ij} \cdot \tilde{\omega}_j) \tag{4}$$

$$\tilde{P}_i = \sum_{j=1}^{n} (\tilde{r}_{ij})^{\tilde{\omega}_j} \tag{5}$$

Step 5. Transformation of fuzzy numbers into crisp numbers.

$$S_i = \left(\frac{S_i^l + 4 \cdot S_i^m + S_i^n}{6} \right) \tag{6}$$

$$P_i = \left(\frac{P_i^l + 4 \cdot P_i^m + P_i^n}{6} \right) \tag{7}$$

Step 6. Calculation of relative weights of alternatives. In this step, three rating strategies are used for generation, namely:

$$\xi_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} \tag{8}$$

$$\xi_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \tag{9}$$

$$\xi_{ic} = \frac{\lambda (S_i) + (1 - \lambda) (P_i)}{(\lambda \max_i S_i + (1 - \lambda) \max_i P_i)}; 0 \leq \lambda \leq 1 \tag{10}$$

The value of λ is usually 0.5. This value can range from zero (0) to one (1).

Step 7. Determination of the final ranking. The best alternative is the one that will have the highest value of the fuzzy CoCoSo method.

$$\xi_i = (\xi_{ia} \cdot \xi_{ib} \cdot \xi_{ic})^{1/3} + \frac{1}{3} (\xi_{ia} + \xi_{ib} + \xi_{ic}) \tag{11}$$

Upon the completion of rankings using the fuzzy CoCoSo method, a comparative analysis will be conducted. This analysis aims to juxtapose the CoCoSo method results with outcomes derived from other fuzzy multi-criteria decision-making methods. To ensure consistency in the comparative process, the same initial decision matrix and criteria weights determined earlier will be utilized. However, the ranking of alternatives will be recalculated using different fuzzy multi-criteria methods. Additionally, a sensitivity analysis is planned. This analysis will focus on varying the individual weights of the criteria to observe the impact of these variations on the ranking of the alternatives.

Table 3. Linguistic values of criteria evaluation by experts

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Expert 1	G	G	VG	VG	G	VG	VG	VG	G	G
Expert 2	M	G	VG	VG	G	G	G	VG	G	G
Expert 3	M	G	VG	G	M	G	G	G	M	G
Expert 4	M	G	G	G	M	G	VG	G	G	M
Expert 5	G	VG	VG	G	G	VG	G	VG	G	G
Expert 6	G	VG	VG	VG	G	VG	VG	VG	G	G
Expert 7	M	G	G	G	M	G	G	G	M	M
Expert 8	M	G	VG	VG	G	G	G	VG	G	G
Expert 9	G	G	VG	VG	G	G	VG	G	VG	G
Expert 10	G	VG	VG	VG	G	VG	G	VG	G	G

4 Results

In the determination of the most suitable location for constructing a logistics center in the Brčko District of BiH, the first step involved the assessment of the significance of various criteria. These criteria were evaluated by experts using linguistic values (refer to Table 3). The experts unanimously agreed on the relevance of each criterion, with the minimum rating assigned being 'medium'. Subsequently, the initial criteria matrix was formulated, and the steps of the fuzzy LMAW method were executed.

This process entailed the transformation of linguistic values into fuzzy numbers, employing a predefined membership function. As a result, the linguistic value 'medium' was converted to the fuzzy number (4, 5, 6), 'good' to (6, 7, 8), and 'very good' (VG) to (8, 9, 9). The anti-ideal point ($\tilde{\gamma}_{AIP}$), which is a value lower than the smallest fuzzy number, was determined. Given that the smallest fuzzy number was 4, the value 3.9 was designated as the anti-ideal point ($\tilde{\gamma}_{AIP}$). All values in the fuzzy initial decision matrix (Expression 1) were divided by this value. The final values of the criteria were then calculated by taking the natural logarithm of the fuzzy vector and dividing it by the natural logarithm of the product of the fuzzy vector for each expert (Expression 2). The results of this methodology indicated that the experts identified 'Connection with multimodular transport' (C3) as the most critical criterion. The criteria 'C4' and 'C8' closely followed in importance (Table 4). These three criteria were deemed most significant in influencing the ranking of alternatives. However, it is noteworthy that the other criteria also exhibited considerable impact on the rankings, underscoring their relevance in the decision-making process.

Table 4. Results of criteria weights obtained by the fuzzy LMAW method

C1	C2	C3	C4	C5
(0.01, 0.05, 0.10)	(0.06, 0.09, 0.13)	(0.08, 0.11, 0.14)	(0.08, 0.10, 0.14)	(0.02, 0.06, 0.11)
C6	**C7**	**C8**	**C9**	**C10**
(0.07, 0.09, 0.13)	(0.07, 0.09, 0.13)	(0.08, 0.10, 0.14)	(0.03, 0.07, 0.11)	(0.03, 0.07, 0.11)

After establishing the weights for each criterion, the evaluation of potential locations was conducted. Mirroring the process used for weighting, experts appraised these locations using predefined criteria and linguistic values (as outlined in Table 5). Subsequent to this assessment, the linguistic values were converted into fuzzy numbers, employing the same membership function previously used. This conversion facilitated the formation of a consolidated decision matrix. The final step in this phase involved normalizing the fuzzy decision matrix, a crucial process that ensures comparability and consistency across the evaluated locations.

Normalization of the fuzzy decision matrix is executed via Expression 3. For instance, when considering the first criterion and the first alternative, it is calculated as follows:

$$\tilde{r}_{11} = \left(\frac{6.6 - 8.0}{8.0 - 6.2} = 0.17; \frac{7.6 - 8.0}{8.0 - 6.2} = 7.2; \frac{8.3 - 8.0}{8.0 - 6.2} = 0.88\right)$$

Following the formation of the normalized fuzzy decision matrix, the values of S_i and P_i are computed. The value S_i is derived by multiplying the normalized decision matrix with the respective criterion weights and subsequently summing these values for each alternative. Conversely, P_i is calculated by multiplying individual values of the normalized decision matrix by the corresponding criterion weights and aggregating these values across the alternatives. Subsequent steps involve converting fuzzy numbers into crisp numbers, as delineated in Expressions 6 and 7. This conversion paves the way for the computation of relative weights of the alternatives, utilizing Expressions 8, 9, and 10. The culmination of this process is the formation of the final ranking, detailed in Expression 11.

Table 5. Initial decision matrix for alternatives

E1	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
A1	G	G	VG	VG	VG	VG	G	G	G	G
A2	VG	G	G	G	G	G	M	M	M	G
A3	G	VG	VG	G	VG	G	G	G	G	G
A4	VG	B	G	M	M	M	B	B	M	M
A5	M	B	VG	G	G	G	M	G	M	G
A6	G	VB	G	G	M	G	G	G	G	G
E2	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
A1	G	G	VG	VG	VG	G	G	G	M	G
A2	VG	VG	VG	G	G	G	G	M	M	G
A3	G	VG	VG	G	G	M	G	G	M	G
A4	VG	B	M	B	M	B	M	B	M	G
A5	G	M	G	G	G	G	G	M	G	G
A6	G	B	VG	VG	G	G	G	G	M	G
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
E10	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
A1	G	G	G	G	G	G	G	G	M	G
A2	G	G	G	G	G	G	G	G	G	M
A3	G	VG	G	G	G	G	G	M	M	G
A4	M	B	M	B	M	B	B	B	G	G
A5	G	M	G	G	G	G	G	G	G	M
A6	G	VB	M	M	M	M	M	M	M	G

The outcomes of this approach, employing both the fuzzy LMAW and CoCoSo methods, indicate that the most favorable location is A1 - Brka-Gajine Zone, as depicted in Table 6. Consequently, this location emerges as the primary choice for establishing logistics centers, with location A3 following closely. Location A4, on the other hand, is identified as the least suitable option.

Table 6. Linguistic values of criteria evaluation by experts

Id	$\tilde{S}_i$	$\tilde{P}_i$	S_i	P_i	ξ_{ia}	ξ_{ib}	ξ_{ic}	ξ_i	**Rank**
A1	(0.30. 0.64. 1.16)	(8.20. 9.72. 9.97)	0.67	9.51	0.18	3.93	0.99	2.58	1
A2	(0.25. 0.57. 1.07)	(8.04. 9.64. 9.92)	0.60	9.42	0.17	3.65	0.98	2.45	3
A3	(0.28. 0.61. 1.13)	(8.85. 9.69. 9.95)	0.64	9.60	0.18	3.84	1.00	2.55	2
A4	(0.01. 0.22. 0.60)	(2.23. 8.84. 9.55)	0.25	7.86	0.14	2.00	0.79	1.58	6
A5	(0.26. 0.57. 1.11)	(7.31. 9.64. 9.93)	0.61	9.30	0.17	3.66	0.97	2.45	4
A6	(0.14. 0.40. 0.86)	(6.79. 9.31. 9.77)	0.43	8.97	0.16	2.91	0.92	2.09	5

To validate these findings, a comparative analysis will be conducted using seven distinct fuzzy methods: Weighted Aggregates Sum Product Assessment (WASPAS), Measurement Alternatives and Ranking according to the COmpromise Solution (MARCOS), Simple Additive Weighting (SAW), Multi-Attributive Border Approximation Area Comparison (MABAC), Additive Ratio Assessment (ARAS), TOPSIS, and Compromise Ranking of Alternatives from Distance to Ideal Solution (CRADIS). This analysis aims to generate rankings through these alternative methods, utilizing the established initial decision matrix and derived weights. These newly formed rankings will then be compared against the ranking produced by the CoCoSo method.

The findings of this comparative analysis (illustrated in Figure 2) reveal that the ranking sequence obtained via the CoCoSo method aligns precisely with that of the TOPSIS method. However, there are variations in the rankings of alternatives A2 and A5 when compared to the other methods. This discrepancy can be attributed to the marginal differences at the third decimal place in the values derived from the CoCoSo method for these two alternatives. Such minor variations are often expected in multi-criteria decision-making processes, especially when dealing with alternatives ranked third or fourth. Therefore, the results of the CoCoSo method are deemed reliable for informing the final decision.

Sensitivity analysis is a critical tool for enhancing decision-making confidence [34]. Its primary objective is to assess how alterations in the weights of criteria impact the ranking of alternatives. Accordingly, various scenarios are developed to test the stability of the ranking order [35]. In this study, the sensitivity analysis involved progressively reducing the weights of individual criteria by 25% until each criterion's weight effectively reached zero. This approach allowed for an evaluation of each criterion's influence on the alternative rankings. The outcomes of this analysis (as depicted in Figure 3) indicated that modifications in the weights of the first three criteria led to a shift in the rankings of alternatives A2 and A5. Across 12 such scenarios, alternative A5 consistently ranked higher than A2. This adjustment in rankings paralleled the results obtained using six other fuzzy methods, thereby affirming the CoCoSo method's alignment with these methodologies. A notable observation was made in 24 scenarios where the weight of the criterion 'Proximity to the urban center' (C6) was altered. In these cases, alternative A3 ascended to the top rank. The rationale behind this shift can be attributed to the fact that alternative A3 is situated further from the urban center than A1. Therefore, when the weight of this particular criterion was reduced in the final scenarios, alternative A3 emerged as the most favorable option. This sensitivity analysis substantiates the findings derived from the fuzzy CoCoSo method, reinforcing the selection of alternative A1 as the prime location for logistics center development, with alternative A3 as the next preferable choice.

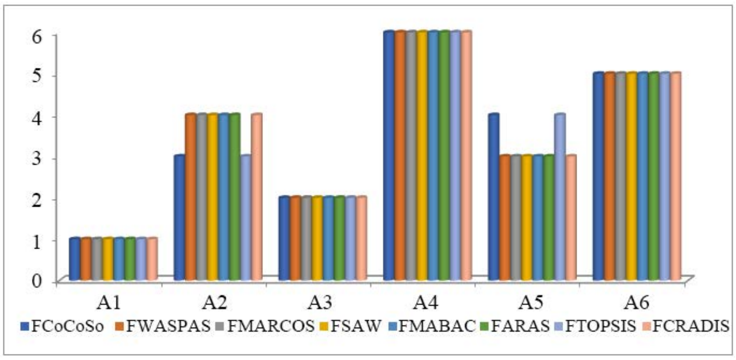

Figure 2. Comparative analysis of the ranking of different fuzzy methods

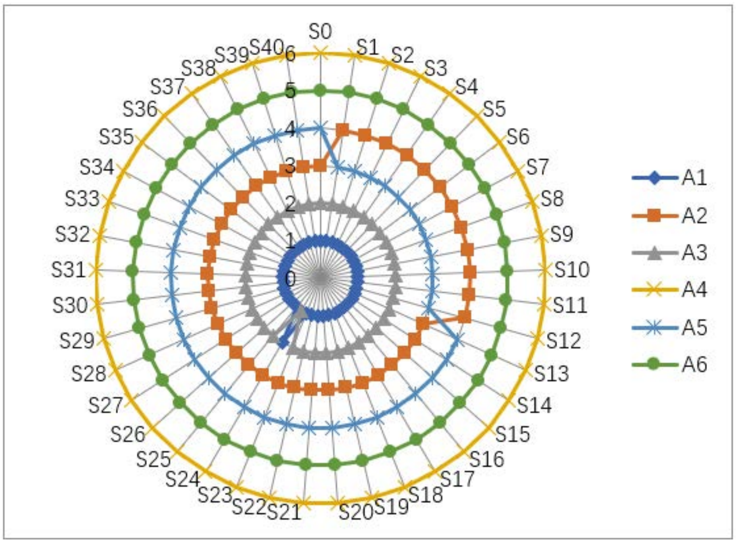

Figure 3. Results of the sensitivity analysis

5 Discussion

The selection of an appropriate location is paramount in establishing a distribution center, particularly in urban logistics, where it plays a critical role in cost reduction [1]. This research specifically targets the Brčko District of BiH, an urban settlement soon to be strategically connected by road to the west and south of Bosnia and Herzegovina and to the Republic of Serbia in the east. This impending connectivity positions the Brčko District for comparative advantages over other regions in Bosnia and Herzegovina, bolstered by its rich trading history.

The Brčko District Government plans to develop 14 business zones, some of which are already active, while others are designated in spatial planning documents [36]. This study has focused on the inactive zones to identify those most suitable for logistics center development. In collaboration with the Government of the Brčko District of BiH, experts from various fields were enlisted to evaluate these business zones. A panel of 10 experts assessed both the importance of criteria and the suitability of alternatives.

To streamline the evaluation process, a unique linguistic value scale, adapted to human cognitive processing [35], was employed for both criteria and alternatives. This five-level scale ranged from 'very bad' to 'very good', enabling experts to articulate their assessments effectively. The fuzzy approach was applied to translate these linguistic evaluations into fuzzy numbers through a defined membership function [37], facilitating the determination of criteria weights and alternative rankings.

In this analysis, 10 criteria were scrutinized using the fuzzy LMAW method. This method diverges from others by eschewing criteria ranking or comparison, relying solely on linguistic evaluations [38]. The findings highlighted the prominence of three criteria: C3 - Connection with multinodular transport, C4 - Availability of roads, and C8 - Transport time, underscoring the significance of comprehensive transport connectivity, road accessibility, and minimized transportation time for logistics efficiency. The Brčko District's unique position, having the only river port in BiH and rail connections to the Republic of Croatia, further emphasizes the importance of multimodal transportation.

The fuzzy CoCoSo method was utilized to ascertain the most suitable location. This method, previously employed in similar studies [21, 27, 31], identified A1 - Zone Brka-Gajine and A3 - Zone Bukvik - south 1 as the top-ranking locations. Their proximity to regional roads and distance from the urban center were influential factors in their rankings, as validated by comparative and sensitivity analyses. However, these rankings may shift with the future development of highway routes, whose official paths and exits are yet to be determined. Subsequent research will be necessary once these routes are finalized. Additionally, the Brčko District Government should consider establishing new business zones closer to the urban center and in alignment with future highway exits, to optimize logistics costs and attract new businesses.

6 Conclusions

This research endeavored to identify the most suitable locations for the establishment of logistics centers in the Brčko District of Bosnia and Herzegovina, focusing on urban logistics. A fuzzy approach was employed, utilizing expert decision-making. The study encompassed ten criteria and six alternatives. The fuzzy LMAW method was applied to determine the significance of these criteria, while the CoCoSo method was utilized for ranking the alternatives. It was observed that the criterion 'C3 - Connection with multi-modular transport' was accorded the highest importance, reflecting the necessity for logistics centers to be well-connected to various modes of transport. Conversely, 'S1 - Land costs' received the least emphasis, owing to the relative similarity in land costs across the locations, diminishing its significance in the decision-making process.

The outcomes of the fuzzy CoCoSo method indicated that Zone A1 - Brka-Gajine emerged as the most favorable location, while Zone A4 - Bodarište was ranked the lowest. The superiority of Zone A1 can be attributed to its strategic placement on a regional road. In contrast, Zone A4, situated in a rural area and being the most distant from the urban center, was not in proximity to major roads, adversely affecting its suitability. A comparative analysis with other fuzzy methods was conducted to validate these findings. This analysis revealed a close alignment between the rankings from the fuzzy CoCoSo and TOPSIS methods. However, discrepancies were noted in the ranking of alternatives A2 and A5, attributed to minor differences in the CoCoSo method's values at the third decimal place. Sensitivity analysis further highlighted that variations in criteria weights particularly influenced the ranking of these two alternatives. Nevertheless, as these locations ranked third and fourth, they did not significantly impact the overall conclusion that Zone A1 is the optimal choice for a logistics center.

The research also acknowledges limitations regarding the selection of criteria and alternatives. While numerous criteria can be considered in evaluating potential logistics center locations, the rationale for selecting specific criteria may be questioned. Future studies should aim to encompass a broader range of criteria to ascertain the most critical factors in location selection for logistics centers. Additionally, the scope of selected locations could be expanded in subsequent research. The Brčko District Government's role in identifying new business zones for potential expansion of logistics and other business activities is pivotal.

Author Contributions

Conceptualization, A.P. and A.B.; methodology, A.P.; software, A.P.; validation, A.B., and I.S.; formal analysis, A.P; investigation, A.P.; resources, A.P.; data curation, I.S.; writing—original draft preparation, A.P.; writing—review and editing, I.S.; visualization, A.B.; supervision, I.S.; project administration, I.S.; funding acquisition, A.B. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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