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Advancing Sustainable Logistics and Transport Systems in Free Trade Zones: A Multi-Criteria Decision-Making Approach for Strategic Sustainable Development

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ABSTRACT

Efficient and sustainable logistics and transportation systems are essential for the success of Free Trade Zones (FTZs), especially in developing regions striving to achieve the Sustainable Development Goals (SDGs). Libya, due to its strategic Mediterranean location and proximity to landlocked African nations, presents a strong case for establishing itself as a regional logistics gateway through the Misurata Free Zone (MFZ). This study proposes an integrated Multi-Criteria Decision-Making (MCDM) model to support SDG-aligned logistics and infrastructure development in MFZ. The Fuzzy Simple Weight Calculation (F-SEWIC) method was used to prioritize seven sustainability-focused criteria, including environmental impact, resilience, economic feasibility, and stakeholder inclusiveness. The Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) method was then applied to assess six strategic development alternatives. Results identified the implementation of a digital cargo tracking platform as the most impactful and sustainable option, followed by the development of green logistics parks and coordinated trucking systems. This research provides a transparent and replicable decision-support model to aid governments, stakeholders, and international development organizations in planning FTZ logistics systems that are efficient, inclusive, and environmentally responsible—supporting SDG 9, SDG 11, and SDG 17.

1. Introduction

Maritime ports are pivotal components of the global economic and trade infrastructure, serving as essential enablers of sustainable development and international commerce. Handling nearly 90% of global goods by volume, these strategic gateways facilitate economic integration, regional connectivity, and resilience in global supply chains. Efficient and modernized port operations not only

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strengthen national economies by expanding access to international markets but also contribute to reducing carbon footprints and enhancing logistic sustainability through innovation and digitalization. Investments in environmentally responsible port infrastructure can significantly improve cargo throughput, minimize logistical bottlenecks, promote green shipping practices, and catalyze inclusive economic growth. These developments stimulate local job creation, support regional development strategies, and increase the attractiveness of host regions to global investors—contributing directly to the achievement of the United Nations Sustainable Development Goals (SDGs), particularly those related to industry, sustainable cities, and global partnerships [1], [2].

Despite their critical role, free trade zones (FTZs) often face logistical inefficiencies due to suboptimal transportation strategies, outdated infrastructure, and regulatory bottlenecks [3]. These challenges are magnified by the dynamic nature of global trade flows and the evolving market demands, necessitating a structured decision-making approach capable of addressing the complexities of modern logistics and transportation systems [4]. Landlocked countries face significant challenges in accessing global markets due to their lack of direct connectivity to major seaports, which limits their ability to engage effectively in international trade [5]. This geographic disadvantage often results in higher transportation costs and logistical complexities, further isolating these nations economically. However, this situation presents a unique opportunity for neighboring countries with coastal access and developed port facilities to act as transit hubs, facilitating trade for their landlocked neighbors and enhancing regional economic integration [6].

Misurata Port in Libya exemplifies such potential. Positioned as a strategic gateway, it offers a critical opportunity to serve as a conduit for landlocked African countries looking to connect with global trade routes [7]. For Misurata Port to capitalize on this opportunity and compete with other international ports, it must significantly enhance its logistical capabilities. This involves upgrading infrastructure, streamlining customs procedures, and improving overall service efficiency to ensure faster, more reliable, and cost-effective transport services. By doing so, Misurata Port can transform from a national asset into a pivotal regional hub, driving economic growth and fostering stronger trade links across the continent [8].

This paper advocates the use of a Multi-Criteria Decision-Making (MCDM) approach to optimize logistics and transportation systems within FTZs. By integrating both quantitative and qualitative criteria into a unified evaluation framework, the MCDM approach enhances the quality and transparency of decision-making, ensuring alignment with strategic objectives and regional development goals. In this study, the Fuzzy simple weight calculation (F-SEWIC) method is employed to determine the relative importance of criteria under uncertainty, effectively capturing expert judgment through linguistic assessments [9]. Following this, the Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) method is applied to rank the alternatives based on their performance relative to both ideal and anti-ideal solutions [10]. This combined methodology offers a structured and comprehensive basis for identifying the most effective strategies to improve logistics and transportation operations within FTZs.

2. Methodology

In recent years, MCDM approaches have gained increasing attention due to their effectiveness in addressing complex decision problems involving multiple, often conflicting criteria [11-13]. These methods have been widely applied across various fields, including transportation and logistics planning, where structured evaluation frameworks are essential [14-16].

This study utilizes a hybrid MCDM approach that integrates F-SEWIC for determining the importance of evaluation criteria and the MARCOS method for ranking potential logistics and transportation strategies. This integrated approach offers a structured yet flexible framework for decision-making under uncertainty, making it particularly suitable for the complex and evolving context of logistics in FTZs such as Misurata. The steps of the hybrid method are outlined as follows:

Step 1: Decision-makers (DMs) assess the relative importance of each criterion by selecting appropriate linguistic terms (e.g., Very Low, Low, Medium, High, Very High), reflecting their expert judgment on the significance of each factor in logistics and transportation performance.

Step 2: The linguistic assessments are then converted into fuzzy numbers using predefined membership functions—commonly in the form of triangular fuzzy numbers. Each term is expressed as a triplet that captures the uncertainty and subjectivity in human judgment by defining lower, middle, and upper bounds.

$$\tilde{x}_{ij} = \left(x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}\right) \tag{1}$$

Where $x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}$ represent the lower, middle, and upper values of the fuzzy number assigned to criterion j by decision-maker i, respectively.

Step 3: The initial fuzzy decision matrix is constructed using the fuzzy numbers obtained from the decision-makers' evaluations. Each element in the matrix represents the performance of an alternative with respect to a given criterion, incorporating the uncertainty captured through the linguistic assessments. This matrix serves as the foundation for both criteria weighting using F-SEWIC and subsequent ranking of alternatives using the MARCOS method.

$$\tilde{A} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \tag{2}$$

Where $\tilde{x}_{ij}$ represents the ranking assigned by the decision-maker to a specific criterion, expressed as a fuzzy number.

Step 4: In this step, all fuzzy values in the decision matrix are normalized by dividing them by the maximum upper bound $\left(\max x_{ij}^{u}\right)$ observed across all criteria and decision-makers.

$$\tilde{n}_{ij} = \frac{x_{ij}^{l}}{\max x_{ij}^{u}}, \frac{x_{ij}^{m}}{\max x_{ij}^{u}}, \frac{x_{ij}^{u}}{\max x_{ij}^{u}} \tag{3}$$

Step 5: The standard deviation $\left(std.dev_{j}\right)$ is calculated for each criterion based on the fuzzy numbers provided by the decision-makers. This measure reflects the variability or consistency in the evaluations for each criterion, allowing the method to emphasize criteria where expert opinions show greater differentiation—an essential feature of the F-SEWIC approach for capturing the relative significance under uncertainty.

Step 6: The normalized fuzzy ratings are multiplied by the corresponding standard deviation values to reflect the influence of each decision-maker's variability.

$$\tilde{v}_{ij} = \tilde{n}_{ij} \times st.dev_j \tag{4}$$

Step 7: The fuzzy-weighted values for each criterion are aggregated by summing the weighted fuzzy evaluations provided by all decision-makers. This aggregation produces a collective representation of each criterion's importance, incorporating both the subjective judgments and the variability captured in earlier steps. The result is a consolidated fuzzy weight for each criterion, which will be used in the next phase to assess and rank the alternatives.

$$\tilde{S}_{ij} = \sum_{j=1}^{n} \tilde{v}_j \tag{5}$$

Step 8: Each individual fuzzy value $\tilde{s}_{ij}$ is divided by the total sum of all fuzzy values to obtain the normalized fuzzy weight for each criterion. During this process, it is essential to maintain the logical order of the fuzzy numbers—ensuring that the lower bound is less than or equal to the middle value, which in turn must be less than or equal to the upper bound.

$$\widetilde{w}_{ij} = \frac{s_{ij}^{l}}{\sum_{j=1}^{n} s_{ij}^{u}}, \frac{s_{ij}^{m}}{\sum_{j=1}^{n} s_{ij}^{m}}, \frac{s_{ij}^{u}}{\sum_{j=1}^{n} s_{ij}^{l}} \tag{6}$$

Step 8: The final fuzzy weights obtained for each criterion can either be retained in their fuzzy form or de-fuzzified into crisp values, depending on the requirements of the subsequent ranking method. Since the MARCOS method requires crisp inputs for comparison and scoring, the fuzzy weights are de-fuzzified using an appropriate method to convert each fuzzy number into a single representative value that reflects the overall importance of each criterion.

$$w_{jdef} = \frac{w_{ij}^{l} + 4 \times w_{ij}^{m} + w_{ij}^{l}}{6} \tag{7}$$

The MARCOS method is designed to evaluate alternatives based on their relative closeness to the ideal and anti-ideal solutions [17]. This approach integrates the concept of a utility function, where each alternative's desirability is measured in relation to these reference points [10]. The ideal solution represents the most favorable performance across all criteria, while the anti-ideal solution reflects the least desirable outcomes. Therefore, the most suitable alternative is the one with the highest utility value, indicating its proximity to the ideal and distance from the anti-ideal.

Step 9: The initial normalized decision matrix is expanded by incorporating both the ideal and anti-ideal alternatives. The ideal solution is composed of the best values observed across all alternatives for each criterion, whereas the anti-ideal solution consists of the worst values. These reference alternatives are essential for assessing the relative performance of each real-world alternative. The ideal and anti-ideal solutions are calculated using the following expressions:

$$AAI = \min_{j} x_{ij} \quad if \;\; j \in B \; and \;\; AAI = \max_{j} x_{ij} \quad if \;\; j \in C \tag{8}$$

$$AI = \max_{j} x_{ij} \quad if \ \ j \in B \ and \ \ AAI = \min_{j} x_{ij} \quad if \ \ j \in C \tag{9}$$

Where B denotes the criterion that should be maximized and C denotes the criteria that should be minimized.

Step 10: The expanded decision matrix, now including both the ideal and anti-ideal alternatives, is subjected to normalization. This step ensures that the values across different criteria—regardless of their units or scales—can be fairly compared. Normalization is performed using the following equations, depending on the nature of the criteria:

$$n\_ij = x\_ai/x\_ij \quad if \ j \in Cc \tag{10}$$

$$n\_ij = x\_ij/x\_ai \quad if \ j \in B \tag{11}$$

The components x_{ij} and x_{ai} denotes the original matrix's variables.

Step 11: The process of determining a weighted matrix. Aggravation is obtained by multiplying scaled matrix variables by the weights assigned to them.

Step 12. The utility degree of the options Ki is calculated. The following formulae are used to calculate the utility degree:

$$K\_i\hat{}-= S\_i/S\_aai \tag{12}$$

$$K\_i\hat{}+= S\_i/S\_ai \tag{13}$$

Where, Si (i=1,2,..,m) denotes the total of the weighted matrix's elements

$$S_i = \sum_{i=1}^{n} v_{ij} \tag{14}$$

Step 13. The process of determining the value functions of the alternatives f (Ki). The following formula is used to compute the value function:

$$f(K_i) = \frac{K_i^+ + K_i^-}{1+\frac{1-f(K_i^+)}{f(K_i^+)}+\frac{1-f(K_i^-)}{f(K_i^-)}} \tag{15}$$

The utility function against the anti-ideal approach is f(K i-), whereas the utility function vs the ideal solution is f(K i+). The following equations are used to determine the valuation models:

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{16}$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{17}$$

Step 14: The final ranking of alternatives is established based on the calculated utility function values. Each utility value reflects the relative performance of an alternative in comparison to the ideal and anti-ideal solutions. Alternatives with higher utility values are considered more favorable, as they indicate greater closeness to the ideal scenario. Therefore, the alternative with the highest utility value is ranked first, representing the most suitable option among those evaluated.

3. Case study

FTZs play a vital role in enhancing international trade, attracting investment, and promoting regional economic integration by offering streamlined regulatory frameworks and specialized infrastructure. Their success depends heavily on the efficiency of logistics and transportation systems that enable the smooth movement of goods between ports, industrial facilities, and inland markets. Libya, due to its central location on the Mediterranean coast and proximity to numerous African landlocked countries, holds significant potential as a regional logistics gateway. In particular, the Misurata Free Zone (MFZ) is strategically positioned to serve as a trade corridor linking sub-Saharan markets with global supply chains [18]. However, realizing this potential requires substantial improvements in its logistics and transportation infrastructure to meet international standards and compete with other regional ports.

To explore viable development strategies, this study evaluates alternative solutions for enhancing logistics and transportation performance within MFZ using a MCDM approach. Seven criteria were selected based on expert consultation and review of relevant literature to ensure a balanced consideration of sustainability, feasibility, and stakeholder relevance. These criteria are: environmental impact (C1), which assesses the ecological consequences of each option; economic cost (C2), reflecting the financial viability and implementation expense; implementation feasibility (C3), measuring how realistically each strategy can be deployed in the current context; stakeholder acceptance (C4), capturing the expected support from logistics companies, policymakers, and local institutions; energy efficiency (C5), focusing on fuel consumption and promotion of renewable alternatives; accessibility and coverage (C6), which evaluates the degree to which each strategy improves logistical reach within Libya and toward neighboring landlocked states; and reduction in congestion (C7), indicating the capacity of each alternative to alleviate bottlenecks around the port and its connecting infrastructure. Based on expert input and relevance to the Libyan context, six transport and logistics development strategies were identified. These include: (S1) the development of a rail freight connection to MFZ to support bulk inland distribution; (S2) the introduction of a coordinated trucking management system to streamline fleet operations; (S3) the expansion of port-adjacent logistics parks to consolidate storage and value-added services; (S4) the implementation of a digital cargo tracking platform to improve supply chain transparency; (S5) the establishment of a dry port or inland terminal to serve as a logistics hub for cargo moving toward the interior; and (S6) the adoption of green logistics initiatives such as incentivizing hybrid and electric transport fleets.

Six experts specializing in port operations, logistics, and transportation planning were consulted to assess the relative importance of the evaluation criteria. Each expert provided judgments using a predefined linguistic scale that was later translated into fuzzy numbers, allowing for the application of the F-SEWIC method. The resulting weights were subsequently used within the MARCOS method to rank the six proposed alternatives according to their overall utility in improving the efficiency and sustainability of logistics and transportation within the MFZ. Table 1 shows the Fuzzy linguistic scale used in this paper.

Table 1. Fuzzy linguistic evaluation scale

Linguistic terms	Membership function
Absolutely bad (AB)	(1,1,1)
Very bad (VB)	(1,2,3)
Bad (B)	(2,3,4)
Medium-bad (MB)	(3,4,5)
Equal (E)	(4,56)
Medium-good (MG)	(5,6,7)
Good (G)	(6,7,8)
Extremely good (EG)	(7,8,9)
Absolutely good (AG)	(8,9,10)
Perfect (P)	(9,10,10)

Table 2. Linguistic decision-making matrix

	C1	C2	C3	C4	C5	C6	C7
E1	G	EG	EG	G	MG	E	G
E2	MG	AG	AG	G	G	G	E
E3	G	EG	AG	EG	MG	E	E
E4	G	G	EG	G	MG	G	G
E5	MG	EG	AG	EG	E	E	G
E6	MG	G	EG	EG	E	G	E

The initial fuzzy decision-making matrix was normalized to ensure consistency in scale across all expert evaluations and criteria. In accordance with the F-SEWIC method, normalization was performed by dividing each fuzzy number by the maximum upper bound observed among all criteria and decision-makers. This process transforms the fuzzy values into a common scale—typically within the [0,1] range—while preserving the proportional differences and importance embedded in the original expert judgments. The normalized matrix eliminates discrepancies caused by differing units or scales, providing a standardized foundation for the subsequent calculation of criteria weights. Table 3 presents the resulting normalized fuzzy decision-making matrix, which forms the basis for the next phase of the analysis.

Table 3. Normalized fuzzy decision-making matrix

	C1	C2	C3	C4	C5	C6	C7
E1	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.5,0.6,0.7)	(0.4,0.5,0.6)	(0.6,0.7,0.8)
E2	(0.5,0.6,0.7)	(0.8,0.9,1.0)	(0.8,0.9,1.0)	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.4,0.5,0.6)
E3	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.8,0.9,1.0)	(0.7,0.8,0.9)	(0.5,0.6,0.7)	(0.4,0.5,0.6)	(0.4,0.5,0.6)
E4	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.5,0.6,0.7)	(0.6,0.7,0.8)	(0.6,0.7,0.8)
E5	(0.5,0.6,0.7)	(0.7,0.8,0.9)	(0.8,0.9,1.0)	(0.7,0.8,0.9)	(0.4,0.5,0.6)	(0.4,0.5,0.6)	(0.6,0.7,0.8)
E6	(0.5,0.6,0.7)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0.4,0.5,0.6)	(0.6,0.7,0.8)	(0.4,0.5,0.6)

The next step in the F-SEWIC method involves multiplying the normalized fuzzy values by the corresponding standard deviation values calculated for each criterion. This step integrates the variability of expert judgments into the weighting process, thereby assigning greater influence to criteria where expert opinions exhibit higher dispersion. Following this multiplication, the resulting fuzzy products are aggregated by summing across all decision-makers for each criterion. This aggregation yields the preliminary fuzzy weights, which reflect the combined importance of each criterion under uncertainty. Throughout this process, attention is paid to maintaining the logical structure of triangular fuzzy numbers—ensuring that the lower bound remains less than or equal to the middle value, and the middle value is less than or equal to the upper bound.

Table 4. Obtaining final values of the criteria by using fuzzy SIWEC method

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
$\tilde{s}_{ij}$	(0.48,0.57,0.66)	(0.61,0.70,0.79)	(0.67,0.76,0.84)	(0.58,0.67,0.76)	(0.43,0.51,0.60)	(0.43,0.52,0.61)	(0.43,0.52,0.61)
$\widetilde{w}_{ij}$	(0.10,0.13,0.18)	(0.13,0.16,0.22)	(0.14,0.18,0.23)	(0.12,0.16,0.21)	(0.09,0.12,0.17)	(0.09,0.12,0.17)	(0.09,0.12,0.17)

Table 5. Defuzzified value of the weights of criteria

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**

w_j	0.1361	0.1664	0.1803	0.1591	0.1228	0.1250	0.1247

The results of the defuzzified weights indicate that Implementation Feasibility (C3) is the most influential criterion, receiving the highest weight of 0.1803. This reflects the critical importance of assessing the practical challenges associated with deploying logistics and transportation solutions within the context of Libyan FTZs, where infrastructure gaps and institutional limitations can significantly hinder implementation. The second most important criterion is Economic Cost (C2) with a weight of 0.1664, underscoring the necessity for financially viable strategies that align with limited public and private sector budgets. Stakeholder Acceptance (C4) follows closely with a weight of 0.1591, highlighting the role of stakeholder engagement, including logistics operators, government agencies, and local communities, in ensuring that proposed initiatives are both supported and sustainable. These results suggest that in the context of FTZ development in Libya, logistical interventions must not only be technically sound and cost-effective but also realistically executable and widely accepted to achieve meaningful, long-term impact.

The initial decision matrix for the MARCOS model, presented in Table 6, was constructed using the average evaluations provided by the experts for assessing the proposed alternatives.

Table 6. The initial decision matrix

Weights of criteria	**0.1361**	**0.1664**	**0.1803**	**0.1591**	**0.1228**	**0.1250**	**0.1247**
Strategies	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
S1	80	90	30	40	70	75	70
S2	75	80	80	80	75	80	70
S3	80	75	80	80	75	75	80
S4	75	70	85	80	80	80	80
S6	80	90	40	50	70	80	70

The data is normalized to make it homogeneous in this phase. Simple linear normalization is the method used in the MARCOS model. The highest value of the criteria is determined for this purpose, as the goal is to maximize these criteria. The normalization matrix is shown in Table (7).

Table 7. The normalized decision matrix

Strategies	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
S1	0.938	0.778	0.353	0.500	0.778	0.938	0.875
S2	1.000	0.875	0.941	1.000	0.833	1.000	0.875
S3	0.938	0.933	0.941	1.000	0.833	0.938	1.000
S4	1.000	1.000	1.000	1.000	0.889	1.000	1.000
S6	0.938	0.778	0.471	0.625	0.778	1.000	0.875

Following the normalization of the initial matrix, the weighted decision matrix is obtained by applying the previously calculated criteria weights. The subsequent step involves calculating the utility scores, which requires identifying both the ideal and anti-ideal solutions—representing the best and worst performance values for each criterion, respectively. The weighted decision matrix, along with the corresponding ideal and anti-ideal solutions, is presented in Table 8.

Table 8. The weighted normalized decision matrix and the negative-ideal solution

Strategies	C1	C2	C3	C4	C5	C6	C7
S1	0.128	0.129	0.064	0.080	0.096	0.117	0.109
S2	0.136	0.146	0.170	0.159	0.102	0.125	0.109
S3	0.128	0.155	0.170	0.159	0.102	0.117	0.125
S4	0.136	0.166	0.180	0.159	0.109	0.125	0.125
S6	0.128	0.129	0.085	0.099	0.096	0.125	0.109
Ideal	0.136	0.166	0.180	0.159	0.123	0.125	0.125
Anti-Ideal	0.113	0.129	0.064	0.080	0.096	0.109	0.109

The next step in the MARCOS model involves calculating the utility function for each alternative. This begins with determining the utility values of both the ideal and anti-ideal solutions, which serve as reference points for evaluating the performance of all proposed alternatives. Based on these calculations, the final ranking of the alternatives is established, as presented in Table 9.

Table 9. The relative assessment matrix and the assessment scores of alternatives

Strategies	K_i^-	K_i^+	F(ki)	Rank
S1	1.031	0.712	0.555	**6**
S2	1.353	0.933	0.728	**3**
S3	1.365	0.942	0.735	**2**
S4	1.429	0.987	0.770	**1**
S5	1.101	0.760	0.593	**4**
S6	1.098	0.758	0.591	**5**

4. Discussion

The results of the MARCOS analysis reveal that Strategy S4, which involves the implementation of a digital cargo tracking platform, emerged as the most preferred option. This outcome may be attributed to the strategy's strong performance across several high-weighted criteria, particularly in implementation feasibility, stakeholder acceptance, and accessibility. The tracking platform is a scalable and relatively low-cost digital solution that can significantly enhance supply chain transparency and efficiency, making it a practical choice in the Libyan FTZ context. Strategy S3, the expansion of port-adjacent logistics parks, ranked second, likely due to its potential to improve cargo consolidation, reduce port congestion, and support value-added services. Strategy S2, the coordinated trucking management system, followed in third place, offering notable benefits in fleet efficiency and traffic flow control. Meanwhile, Strategies S5 and S6, the establishment of a dry port and the adoption of green logistics practices, ranked fourth and fifth, respectively. Although environmentally and operationally valuable, these alternatives may face challenges related to infrastructure requirements and initial investment costs. Strategy S1, the development of a rail freight connection, was ranked lowest, possibly due to its high implementation cost and longer time horizon, which may not align with Libya's current logistical capabilities and funding priorities.

5. Conclusion

This study presented a structured decision-making framework to evaluate and prioritize logistics and transportation development strategies within FTZs, using the MFZ in Libya as a case context. By integrating the F-SEWIC method to determine criteria weights and the MARCOS method to rank alternatives, the study offers a robust approach to managing uncertainty and complexity in transport planning. Seven evaluation criteria were identified, reflecting key dimensions such as implementation feasibility, economic cost, environmental impact, and stakeholder acceptance.

The analysis demonstrated that digital and operational strategies, particularly the implementation of a digital cargo tracking platform (S4), are currently the most viable and impactful solutions. This was followed by the expansion of port-adjacent logistics parks (S3) and the introduction of a coordinated trucking management system (S2). These findings highlight the importance of prioritizing scalable, cost-effective, and technology-driven interventions in resource-constrained environments like Libya, where logistical challenges are compounded by institutional and infrastructural limitations.

The proposed framework not only aids policymakers and stakeholders in selecting appropriate strategies for MFZ but also provides a replicable model for other free zones aiming to enhance their logistical performance. Future research could extend this analysis by incorporating dynamic factors such as geopolitical risk, investment trends, or real-time cargo flow data, further enhancing the strategic planning process for logistics development in emerging economies. In addition, the extensions of MCDM method could be applied in the future works, such as, parsimonious spherical fuzzy analytic hierarchy process (AHP) [19], Z-number extension of Parsimonious Best Worst Method [20] and magnitude-based fuzzy AHP [21].

Author Contributions

Conceptualization, I.B., Q.Y and M.B.; methodology, I.B., and W.Q; validation, M.B. and Q.Y.; formal analysis, M.B, W.Q and I.B.; writing—original draft preparation, I.B., Q.Y and W.Q; writing—review and editing, M.B.; visualization, M.B. and Q.Y; project administration, I.B. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

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

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