Enhancing Disaster Management through Effective Warehouse Location Selection using Linguistic Decision Making: An Integrated Approach

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Abstract

Effective warehouse location selection is a critical component of disaster management, as it can significantly impact the efficiency and effectiveness of disaster response efforts. This paper proposes an integrated approach based on linguistic decision making (LDM) for assessing and prioritizing key criteria for warehouse location selection in disaster management. Specifically, the 2-Tuple linguistic (2-TL) model is used to represent decision-maker's subjective opinions, and then an integrated methodology combining 2-TL-DEMATEL and 2-TL-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is employed for the analysis of the criteria and the selection of the optimal warehouse location. This approach allows decision-makers to effectively deal with subjective linguistic information and to handle uncertainty and imprecision in the decision-making process. The proposed methodology combines DEMATEL for causal relation analysis and TOPSIS for multi-criteria decision-making to identify and select the optimal warehouse location. Moreover, the paper provides a case study conducted in the Türkiye area to demonstrate the practical application of the proposed methodology. The results of the study provide an importance ranking of the key location selection criteria and reveal the causal relationships between them. The paper concludes that the proposed methodology can provide a structured and systematic approach for warehouse location selection in disaster management, and it can help decision-makers to improve the efficiency and effectiveness of disaster response efforts.

Keywords
2-Tuple linguistic model, Causal relationship analysis, Disaster management, Multi-criteria decision-making, Warehouse location selection.

1. Introduction

Disaster management is a critical aspect of ensuring the safety and security of communities and minimizing the impact of natural and anthropogenic disasters (Lillywhite et al., 2022). Effective disaster management requires a comprehensive strategy that includes various stages, from prevention and preparedness to response and recovery. One critical component of disaster management is warehouse location selection for the storage and distribution of relief goods and supplies.

The selection of an appropriate warehouse location is crucial for effective disaster management. The location of a warehouse can significantly impact the response time, accessibility, and effectiveness of relief efforts (Geng et al., 2021). Disaster logistics and supply chain management play a critical role in ensuring the efficient and effective delivery of relief supplies to affected areas. The warehouse location is a key factor in determining the efficiency and effectiveness of the logistics and supply chain management for disaster relief operations.

Warehouse location selection is a multi-criteria decision-making problem (MCDM) that requires the consideration of various factors, such as the distance to disaster-prone areas, transportation infrastructure, available storage space, and cost-effectiveness. Failure to select an optimal warehouse location can result in delays in the delivery of relief supplies, increased transportation costs, and inefficiencies in relief operations (Yaman et al., 2020).

MCDM is a powerful approach for addressing complex decision-making problems that involve multiple criteria and alternatives. In the context of warehouse location selection for disaster management, MCDM can help decision-makers evaluate and prioritize potential warehouse locations based on multiple criteria and objectives. Moreover, Linguistic decision-making (LDM) is a useful extension of MCDM that incorporates subjective evaluations and preferences of decision-makers in the decision-making process. LDM allows decision-makers to express their judgments using linguistic terms, such as "very good," "bad," "fair," "equal importance," etc. The 2-Tuple linguistic (2-TL) model (Herrera et al., 2000) is a well-known LDM method that can effectively handle uncertain and imprecise information in decision-making. The integration of the 2-TL model with MCDM can provide decision-makers with a more comprehensive and accurate evaluation of related problem. The 2-TL model can capture the subjective evaluations of decision-makers, while MCDM can handle multiple criteria and objectives (Martínez et al., 2015). The integration of the two approaches can help decision-makers overcome the limitations of traditional MCDM methods, which often assume precise and certain information (Herrera et al., 2000).

1.1 Objectives

Effective disaster management relies on a well-designed and well-executed response plan that includes various stages from prevention and preparedness to response and recovery (Rosenblum et al., 2023). As aforementioned, one key component of disaster response is the selection of an appropriate location for warehousing and distributing relief goods and supplies. To address this critical issue, this paper aims to develop key criteria for assessing warehouse location options for disaster management. The criteria were derived from the “disaster management” literature. The selected criteria will be analyzed and prioritized using the 2-TL-DEMATEL methodology, which provides a systematic and structured approach to analyze the interrelations among the criteria (Abdullah et al., 2019). This approach will allow for the identification of the most critical factors that influence the effectiveness of warehouse location selection for disaster management. After the key criteria have been identified and prioritized, the 2-TL-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methodology will be applied to select the most appropriate warehouse location. This methodology is a well-established MCDM approach that considers both the benefits and drawbacks of each location option to determine the most suitable location for disaster management.

Moreover, in addition to the location selection process, this paper will also provide a causal relation analysis for the key location selection criteria. This analysis will reveal the cause-and-effect relationships between the criteria and provide insights into the underlying mechanisms that influence the effectiveness of warehouse location selection for disaster management. The results of this study will not only provide decision-makers with a framework for selecting the optimal warehouse location for disaster management, but it will also provide insights into the underlying factors that influence the effectiveness of disaster response efforts.

The use of 2-TL integrated MCDM approaches for warehouse location selection offers several benefits. First, it enables decision-makers to incorporate subjective evaluations and preferences into the decision-making process, leading to more accurate and relevant evaluations of potential warehouse locations (Rath et al., 2014). Second, the integration of these approaches provides a more comprehensive evaluation of potential warehouse locations, ensuring that the selected location meets the needs of relief operations. Third, the integration of these approaches can facilitate stakeholder participation, allowing for the inclusion of various perspectives and preferences in the decision-making process (Martínez et al., 2015).

To achieve the aforementioned objectives, the paper is organized as follows: Section 2 presents a review of the recent literature on disaster management and warehouse location selection. This section provides an overview of the key concepts, theories, and previous studies related to this field. Section 3 provides a detailed explanation of the suggested integrated 2-TL-DEMATEL-TOPSIS methodology. This section outlines the steps involved in this methodology, including the identification and prioritization of key criteria, the causal relationship analysis, and the application of the TOPSIS method to select the optimal warehouse location. Section 4 presents a case study that was conducted in the Türkiye area to demonstrate the practical application of the proposed methodology. Section 5 presents the results of the study and provides a detailed discussion of the findings. Finally, Section 6 provides the conclusions of the study and summarizes the main contributions of this research. This section also highlights the limitations of the study and provides recommendations for future research.

2. Literature Review

This section provides a literature review of studies related to disaster management, warehouse location selection, and the use of MCDM approaches in this area. First, previous research on disaster management is reviewed, followed by an analysis of studies focused on warehouse location selection. Lastly, studies that have utilized MCDM approaches for warehouse location selection are examined.

2.1 Disaster Management

Disasters, whether caused by natural or human factors, can cause significant damage to people, communities, and infrastructure. Effective disaster management is critical to minimize the impact of disasters and facilitate a quick recovery. Disaster management involves a coordinated effort across various sectors, including emergency response, healthcare, logistics, and supply chain management (European Commission, 2022). Over the years, numerous studies have been concentrated on this area.

To gain a comprehensive understanding of the current state of the disaster management literature, a keyword search was conducted on the Scopus[1] database without any year restrictions using the keyword "Disaster management". All review papers were analyzed through a keyword occurrences analysis using VOSViewer[2] to obtain a clear picture of the highly concentrated keywords/areas in the disaster management field. As shown in Figure 1, the analysis revealed two distinct clusters in the disaster management area. The keywords within these clusters demonstrated that two major areas are important for disaster management: Physical requirements and Organizational requirements (European Commission, 2022).

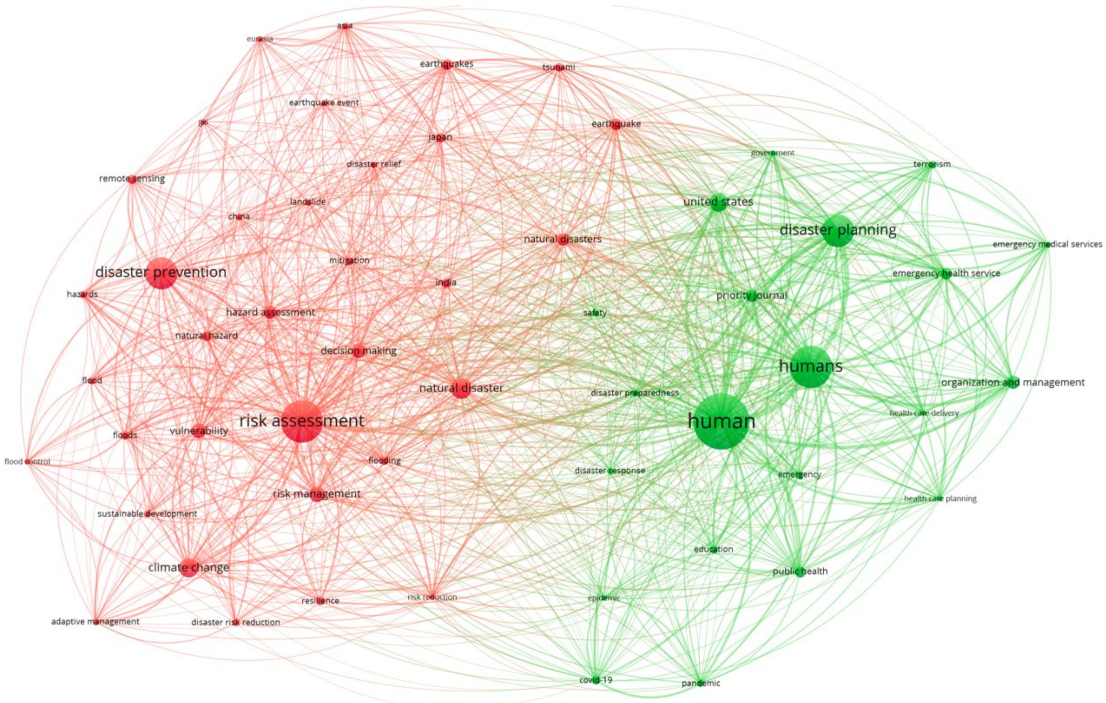


Figure 1. Co-occurrences of keyword in disaster management area

The red cluster is primarily concerned with the physical requirements of disaster management, which include actions related to disaster mitigation, risk assessment, and disaster prevention (Lillywhite et al., 2022; Munawar et al., 2022; Durrant et al., 2022). This group of studies emphasizes the importance of building resilience in disaster-prone

[1] https://www.scopus.com
[2] https://www.vosviewer.com

countries, such as India , Japan (Daimon et al., 2023), and Malaysia (Nasir et al., 2023; Ligong et al., 2022), and focuses heavily on flood and earthquake disasters, which are prevalent in these regions. Furthermore, climate change is increasingly recognized as a potential risk factor for disaster management (Rolnick et al., 2023; Tschakert et al., 2023). It is noteworthy that the disaster management process is closely tied to the principles of sustainable development, as highlighted in the literature (Priyanti et al., 2022; Abdullah-Al-Mahbub et al., 2023; Asadzadeh et al., 2022; Rezvani et al., 2023; Zeng et al., 2022). Overall, the review underscores the need for a holistic approach to disaster management that integrates physical and organizational requirements to achieve resilience and sustainability in the face of natural disasters.

The second cluster in Figure 1 primarily focuses on organizational requirements, with a strong emphasis on the pre- and post-disaster processes (Akhshik et al., 2023; Takefuji, 2023). The studies in this cluster concentrate on the impact of disasters on human life, and the pre-disaster actions mainly include public health, education, and preparedness (Sawalha, 2023; Ramasamy et al., 2022; Pastrana-Huguet et al., 2022; Lillywhite et al., 2022). Additionally, the post-disaster processes mainly involve emergency medical services (Heydari et al., 2022; Ries, 2022) . Recent studies have primarily focused on the emergency health services aspect, especially due to the pandemic that occurred in 2019 (Sheek-Hussein et al., 2023; Sayfouri et al., 2023). Terrorism is also considered a potential disaster, and several review papers in this area have explored the topic in-depth (Alexander, 2003). Overall, this cluster highlights the importance of organizational preparedness and response in effectively managing disasters.

2.2 Warehouse Location Selection

Numerous studies have emphasized the critical role of warehouse locations in effective disaster management and planning. Therefore, this study aims to investigate the criteria and causal relationships that determine optimal warehouse locations in disaster-prone regions. A keyword search for "disaster" and "warehouse location selection" on Scopus database yields three relevant studies. These studies emphasize the importance of selecting appropriate warehouse locations to ensure timely and effective delivery of relief materials during disaster situations.

Two studies (Yaman et al., 2020; Boonmee et al., 2020) focus on warehouse location selection in 2020. Yaman et al., targets to evaluate factors affecting the warehouse location. The study uses fuzzy approach with Pythagorean Fuzzy sets integrated with DEMATEL approach which is a MCDM methodology. The main factors detected in this study for warehouse selection are structure of land, service availability, geographical location, distance to customs or ports, climate, natural disaster risk, social structure of the environment, distance to service markets, infrastructure availability, distance to hospitals and pharmacies. Additionally, since the study focuses on medical materials and services, additional criteria specific to medical issues may also be taken into consideration by decision-makers. Boonmee et al., approached the warehouse location problem with a multi-objective fuzzy mathematical programming. The proposed model focuses on minimizing the response time and planning budget, determining the location of warehouses, total inventory to be stored, and distributed management of the warehouses. The study validates the proposed model using a real case study in Pichit province, Thailand and presents several alternatives to decision-makers.

More recently, a sustainable warehouse location selection model is proposed by (Mittal et al., 2023). Mittal et al., also suggested a MCDM based methodology for location selection. The study emphasizes the importance of including social and environmental factors in addition to traditional criteria such as cost and logistics in decision-making related to warehouse location selection. They used Best Worst Method and TOPSIS for ranking the potential locations.

Recent studies on warehouse location selection in disaster management show that the MCDM approach is widely used due to its ability to evaluate a subject based on multiple dimensions. This approach allows decision-makers to consider various factors and criteria that are important in the decision-making process, such as cost, logistics, environmental, and social criteria. The MCDM approach can help organizations to select optimal warehouse locations that can efficiently and effectively provide aid during disaster situations, thereby contributing to improved disaster management. In line with recent studies on warehouse location in disaster management, this study proposes the use of a MCDM methodology. However, it differs from other studies by integrating the LDM with the 2-TL model. This model is more flexible and aligns with human cognitive processes, providing a more relaxed environment for investigating and evaluating the relevant dimensions and criteria (Martínez et al., 2015). Table 1 presents the key factors and dimensions that have a significant impact on the selection of warehouse locations for humanitarian logistics. The factors/dimensions listed in Table 1 are based on a review of the relevant literature on disaster management and humanitarian logistics.

Table 1: Factors Effecting Warehouse Location Selection

Factors Effecting Warehouse Location Selection			
C1	Closeness to disaster zone (Mittal et al., 2023; Yakici et al., 2021)	**C8**	Closeness to the (potential) victims (Onggo et al., 2021)
C2	The accessibility of experienced logistics professionals (Rivera et al., 2019; Rath et al., 2014)	**C9**	Land cost (Roh et al., 2013)
C3	Warehouse security (Yaman et al., 2020)	**C10**	Storage cost (Roh et al., 2013)
F4	Geolocation (Ye et al., 2015; Gao, 2021)	**C11**	Labor cost (Roh et al., 2013)
C5	Transportation network (Geng et al., 2021; Horner et al., 2010)	**C12**	Association with logistics facilitators
C6	Seaport and airport accessibility (Geng et al., 2021; Horner et al., 2010)	**C13**	Technological infrastructure for connectivity
C7	Storage capacity (Wang et al., 2020; Hakim et al., 2018)	**C14**	Climate (Horner et al., 2010; Yaman et al., 2020)
		C15	Urban access convenience (Geng et al., 2021; Horner et al., 2010)

3. Methods

This section provides a detailed description of the methodology proposed in this study. Firstly, an overview of the suggested methods is presented, followed by the detailed steps, which can be found in Figure 2.

3.1 Data Collection

The data utilized in this study was obtained from both academic and grey literature sources. The grey literature included reports from both industrial and non-governmental organizations pertaining to disaster management and warehouse location selection. In addition, expert assessments were gathered through the utilization of the Delphi method (Gossler et al., 2019). Meetings were conducted with the experts to create a flexible environment where they could provide feedback and discuss the suggested model and assessments.

3.2 2-Tuple Linguistic Model

The 2-TL model is a fuzzy logic-based model (Zadeh, 1965) that converts linguistic data into numerical form without losing information. It represents linguistic information with a 2-tuple form of *(s, α)*, where 's' is a linguistic label and 'α' is a numerical value. For the necessary and basic definitions, readers can refer to (Martínez et al., 2015). The leading translation equation of 2-TL is given as follows:

$$\Delta_s : [0, g] \rightarrow \bar{S}$$
$$\Delta_s(\beta) = (S_i, \alpha), \text{with} \begin{cases} i = round(\beta) \\ \alpha = \beta - i \end{cases} \quad (1)$$
$$S_i \in S \Rightarrow (S_i, 0)$$

Linguistic Hierarchies

A *Linguistic Hierarchy (LH)* is the union of all levels *t,* where each level *t* corresponds to a linguistic term set symmetrically distributed with an odd granularity (Martínez et al., 2015). The transformation function to translate a linguistic term set with granularity *n(t)* to a linguistic term set having granularity *n(t')* is as follows:

$$TF_{t'}^{t} = \left(S_i^{n(t)}, \alpha^{n(t)}\right) = \Delta\left(\frac{\Delta^{-1}\left(\left(S_i^{n(t)}, \alpha^{n(t)}\right) \times (n(t') - 1)\right)}{n(t) - 1}\right) \quad (2)$$

The transformation function enables multi-granular information to become one linguistic domain.

3.2 DEMATEL

The DEMATEL (Gabus et al., 1972) method is a precise MCDM tool that identifies the significance of the criteria used in the decision-making process. It allows for the determination of the causal relationships between the evaluation criteria and is recommended for the criteria weighting process. This study employs DEMATEL in its framework due to its ability to examine the interdependence among the proposed criteria and extract their interrelationships (Abdullah et al., 2019). These interrelationships can be useful in enhancing the efficiency of the evaluation process. The evaluation dimensions were selected through a comprehensive literature review and interviews with industry experts.

3.3 TOPSIS

The TOPSIS (Hwang et al., 1981) is a widely used MCDM method that ranks the alternatives by measuring their distance from both the ideal and non-ideal solutions (Büyüközkan et al., 2017). The ideal solution is the one with the maximum benefit or the highest value for the decision-maker, while the non-ideal solution is the one with the minimum benefit or the lowest value. The overall index is calculated based on these distances, and the alternatives are ranked accordingly. TOPSIS method is based on the assumption that the ideal solution lies somewhere in the middle of the range of the decision-making criteria. The closer the alternatives are to the ideal solution and the farther away from the non-ideal solution, the better they are ranked. This method is particularly useful for solving problems with multiple criteria and multiple alternatives, where the decision-maker aims to find the best alternative that satisfies all the criteria.

3.4 Group Decision Making

MCDM aims to determine the most suitable alternative by considering multiple criteria simultaneously. Group decision-making (GDM) may be necessary to reach a collective decision in this process, particularly when decision-makers (DMs) have different backgrounds and perspectives. GDM involves a shared understanding among DMs to work together towards a common goal (Büyüközkan et al., 2015). However, reaching a consensus in a group with diverse opinions can be challenging, especially when facing ambiguity and uncertainty. Traditional GDM methods, such as majority rule, minority rule, or total agreement, may not guarantee an acceptable solution for all DMs.

To address this issue, this study adopts a consensus-reaching process using the Delphi approach. Delphi is a communication tool that facilitates group decision-making, particularly in complex and uncertain problems (Büyüközkan, 2004). The method leverages expert knowledge and involves a group of knowledgeable and experienced contributors. As the DMs' assessments are based on their subjective judgments, the study employs linguistic variables instead of crisp numbers to represent the uncertain and subjective nature of the data. Through the Delphi process, the study ensures that the selected warehouse location is acceptable to all DMs and leverages the expertise of the group to improve the decision-making process.

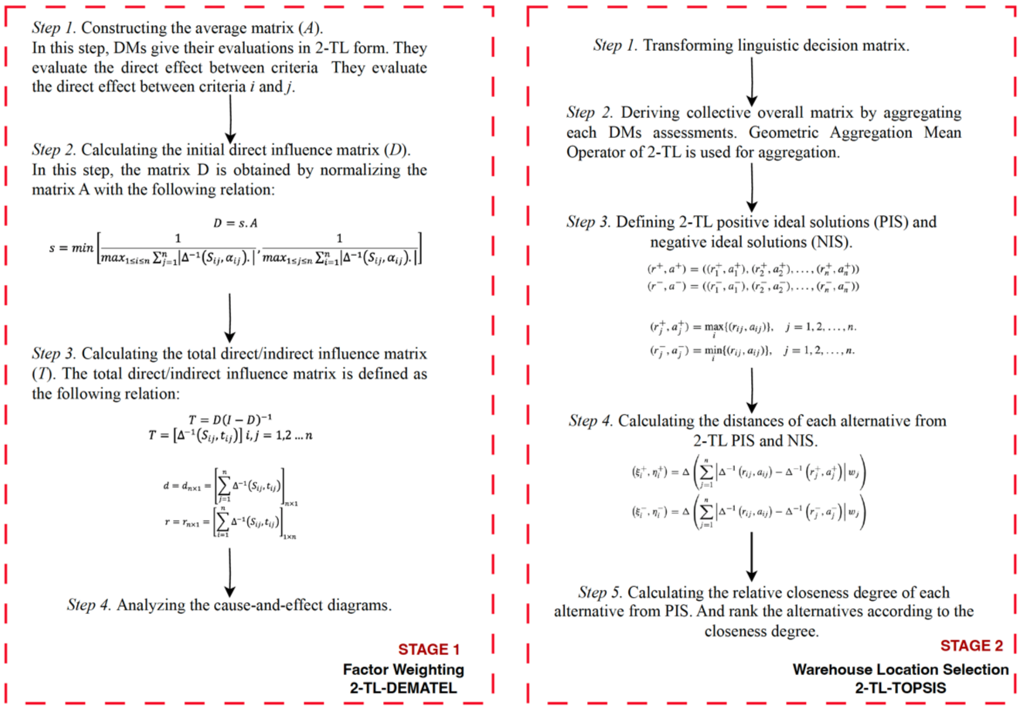


Figure 2. Suggested integrated2-TL-DEMATEL-TOPSIS methodology.

4. Case study

In this section, a case study is presented from Türkiye, which is a country prone to disasters and has recently experienced two major earthquakes, highlighting the need for improved planning and organization in disaster response. One of the main challenges faced in post-disaster processes was the lack of warehouses located closer to the affected areas. To address this issue, the proposed framework was applied in the Kahramanmaraş region. Six potential warehouse locations were identified through expert input for the decision-making problem, and the steps outlined in the previous section were then followed to obtain the results.

In this case study, a team of experts with diverse backgrounds and expertise were assembled. Two of the decision makers were seasoned academicians with extensive experience in supply chain, logistics, and humanitarian logistics. As a result, these experts utilized a linguistic scale with a high degree of granularity to provide their evaluations. Another expert was a consultant who possessed considerable experience in supply chain, and as a result, her evaluations were based on a linguistic variable set with lower granularity. Table 2 provides a comprehensive overview of the linguistic sets used in the 2-TL-DEMATEL-TOPSIS methodology by the experts. These sets were utilized to represent the subjective nature of the evaluation criteria and to mitigate the impact of uncertainty and vagueness. The experts' assessments were based on their judgment, and the use of linguistic variables aided in minimizing the potential for bias in the decision-making process.

Table 2. Five and nine scaled linguistic evaluation sets[3]

2-TL linguistic sets	
S^5	*None (N)-Low(L)- Medium/Equal (M))- High(H)-Perfect(P)*
S^9	*None (N)-Low (L)-Medium Low (ML)-Almost Medium (AM)- Medium (M)-Almost High (AH)-High(H)- Very High (VH)-Perfect(P)*

5.1 Results and Discussions

After completing the first stage of the analysis using 2-TL-DEMATEL, crisp values were obtained and shown in Figure 3. The factor with the highest value was identified as the most significant factor for warehouse location

[3] Instead of using the "Medium" linguistic variable, the "Equal" variable is employed for the DEMATEL assessments.

selection. However, according to DEMATEL, a more in-depth analysis is needed to investigate the causal relationships between the factors. Based on the initial analysis, it can be inferred that the technological infrastructure is the most critical factor for selecting the warehouse location.

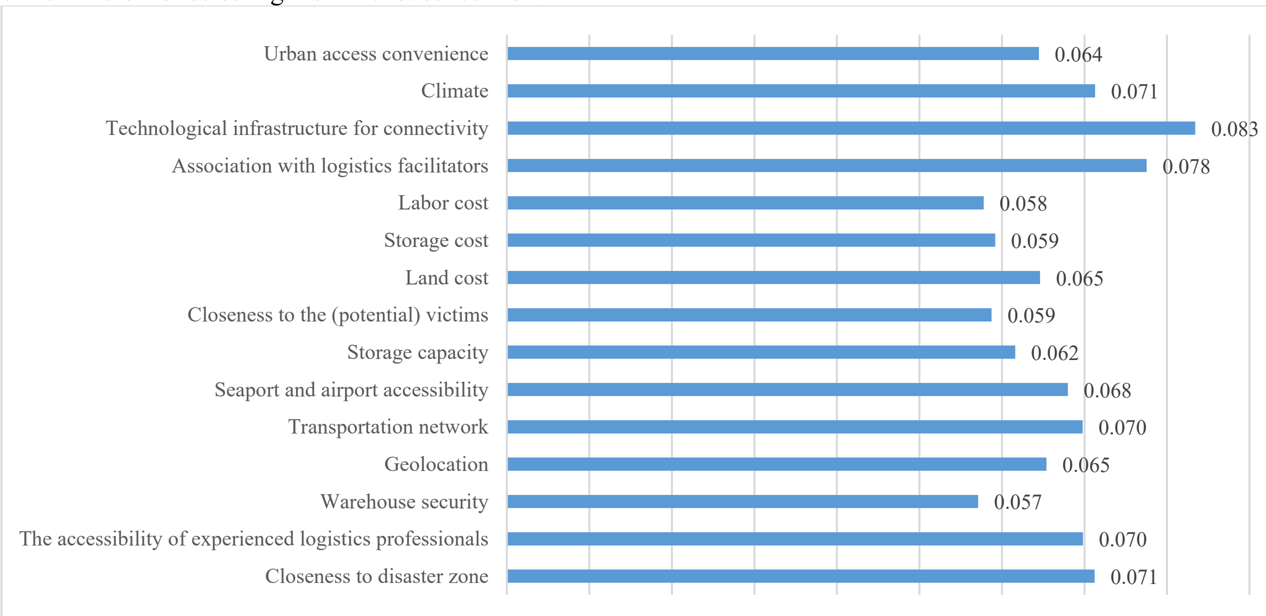
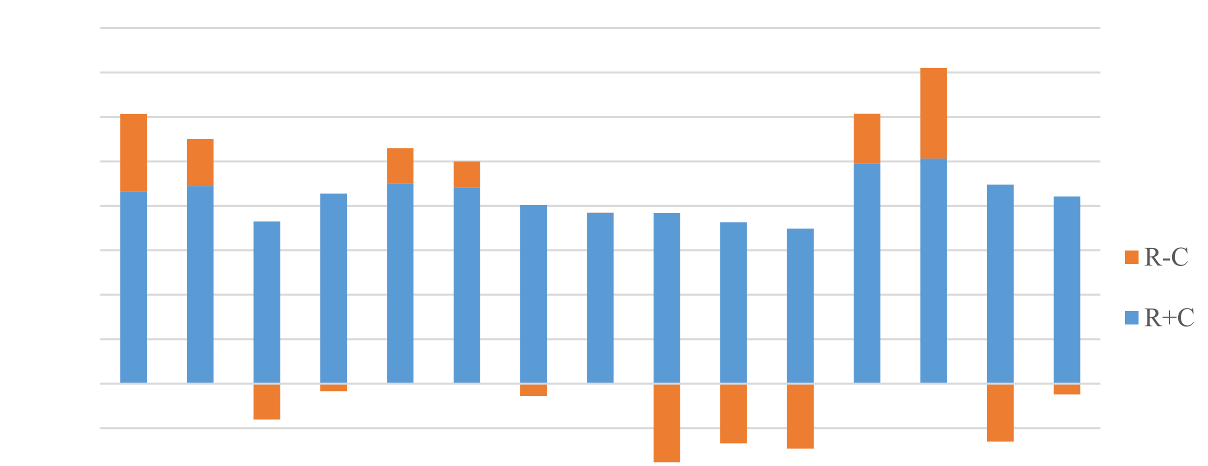


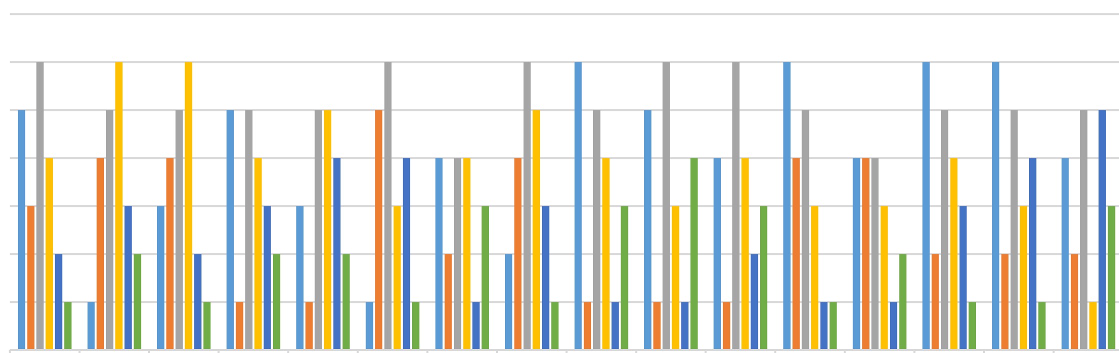
Figure 3. Crisp results for factor prioritizations



	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
R-C	0.875	0.530	-0.40	-0.08	0.402	0.294	-0.13	0.000	-0.88	-0.67	-0.73	0.563	1.018	-0.65	-0.12
R+C	2.159	2.222	1.824	2.138	2.247	2.204	2.010	1.922	1.920	1.816	1.743	2.473	2.532	2.239	2.106

Figure 4. *d*+*r* and *d*-*r* values for factors

If the result of the (r-c) calculation is greater than zero, it implies that the degree of influence on other factors is greater than the degree of being influenced by them. Figure 4 demonstrates that C1, "closeness to the disaster zone," has the highest (r-c) values, indicating its influence on other factors. Therefore, prioritizing technological infrastructure alone will not be sufficient for location selection. Instead, factors C1, C2, C4, C6, C12, and C13 should be given priority since they have a significant impact on other factors. Further analysis will be presented in the following section. The 2-TL-TOPSIS method is utilized for the location selection process, and the obtained results and sensitivity analysis are presented in Figure 5.



	Case Study	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12	Case 13	Case 14	Case 15
W1	5	1	3	5	3	1	4	2	6	5	4	6	4	6	6	4
W2	3	4	4	1	1	5	2	4	1	1	1	4	4	2	2	2
W3	6	5	5	5	5	6	4	6	5	6	6	5	4	5	5	5
W4	4	6	6	4	5	3	4	5	4	3	4	3	3	4	3	1
W5	2	3	2	3	4	4	1	3	1	1	2	1	1	3	4	5
W6	1	2	1	2	2	1	3	1	3	4	3	1	2	1	1	3

Figure 5. Case study results and sensitivity analysis.

The sensitivity analysis conducted on the suggested model demonstrates its robustness under varying conditions, such as changes in criteria weights. Each case examined in the case study emphasizes the significance of one factor for location selection. When considering all possible scenarios within 15 different scenarios, the fourth warehouse is consistently ranked as the top alternative. Further assessments will be given during the presentation.

6. Conclusion

In conclusion, this paper proposed a 2-TL-DEMATEL-TOPSIS methodology for warehouse location selection in disaster-prone regions. The proposed methodology combines linguistic variables and multiple criteria decision-making techniques to provide a comprehensive analysis. The case study in the Kahramanmaraş region of Türkiye showed that the technological infrastructure and proximity to the disaster zone are crucial factors in warehouse location selection. Additionally, the sensitivity analysis demonstrated the robustness of the proposed methodology under different scenarios.

From a managerial perspective, the results of this study provide decision-makers with valuable insights into the critical factors to consider when selecting warehouse locations in disaster-prone regions. By understanding the importance of factors such as technological infrastructure and proximity to the disaster zone, decision-makers can better plan and organize the post-disaster process. Future research can expand the proposed methodology by incorporating additional criteria and comparing it with other methods. Additionally, case studies in other disaster-prone regions can provide a better understanding of the applicability of the proposed methodology.

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