Advancing Humanitarian Logistics Design through Linguistic Decision-Making based Quality Function Deployment

Gülçin Büyüközkan
Professor, Department of Industrial Engineering
Galatasaray University
Ortaköy, Istanbul, Turkey
gbuyukozkan@gsu.edu.tr

Deniz Uztürk
Department of Management, Business Research Center
Galatasaray University
Ortaköy, Istanbul, Turkey
duzturk@gsu.edu.tr

Abstract

This paper proposes an innovative approach to designing effective humanitarian logistics systems based on linguistic decision-making. The authors aim to create a detailed roadmap for such systems by carefully considering the key needs that must be addressed. To accomplish this, they utilize the House of Quality (HoQ) method of Quality Function Deployment (QFD), which establishes clear relationships between the various needs of humanitarian logistics and the specific requirements for designing effective systems. The inherently chaotic and complex nature of humanitarian logistics presents a significant challenge to effective design. However, the use of linguistic variables, combined with fuzzy logic-based techniques, can help to handle the vagueness and ambiguity of the field. The paper suggests using the 2-Tuple Linguistic (2-TL) model in combination with QFD technique to create more effective roadmaps that can be followed even in the face of uncertainty and unexpected events. This paper contributes to the existing literature by proposing a linguistic-based design approach to prioritize the design requirements for humanitarian logistics systems. This approach can guide practitioners to generate relevant strategies to address critical design requirements. The paper also presents a case study from Türkiye to develop the proposed QFD models for humanitarian logistics design and provides further discussions and analysis at the end.

Keywords
2-Tuple Linguistic, Group decision-making, QFD, Humanitarian logistics, Linguistic decision-making

1 Introduction
Humanitarian logistics is a critical aspect of disaster relief efforts, aimed at delivering aid to those in need in a timely and efficient manner (de Camargo Fiorini et al., 2022). For example, during natural disasters like earthquakes or hurricanes, humanitarian logistics is crucial for providing food, water, shelter, and medical supplies to affected populations. Similarly, during conflict situations, humanitarian logistics is necessary for providing aid to refugees and internally displaced persons (European Commission, 2022).

However, the uncertain and complex nature of humanitarian crises presents significant challenges to the design of effective logistics systems. For example, in the aftermath of a natural disaster, road and communication networks may be severely disrupted, making it difficult to transport aid to affected areas. Similarly, in conflict situations, insecurity and violence may make it dangerous or even impossible for aid workers to reach those in need. In such contexts, it can be difficult to establish clear guidelines and protocols for the design of effective logistics systems. In order to address these challenges, innovative approaches are required to prioritize the design requirements for humanitarian logistics systems (Schiffling et al., 2022). One such approach is based on linguistic decision-making, which involves using linguistic variables to help make decisions in uncertain and complex contexts (Herrera and Martinez, 2000). Linguistic decision-making can be particularly useful in humanitarian logistics, where the inherent chaos and ambiguity of the field can make it difficult to establish clear guidelines and protocols for effective design (Zadeh, 1975).

The Quality Function Deployment (QFD) method is suggested to prioritize the design requirements for humanitarian logistics systems. QFD is a structured approach to design that helps to ensure that the design of a product or system meets the needs and expectations of its users (Akao, 1990). By creating a matrix that relates the various needs of the users to the specific design requirements of the product or system, QFD prioritizes the most important and critical design requirements, thus ensuring that the product or system is designed in a way that meets the needs and expectations of its users.

In the context of humanitarian logistics, QFD can be used to identify the most critical skills and requirements for effective design. For example, the QFD matrix may include needs such as timely delivery of aid, efficient transportation of goods, and effective communication between aid workers. Each of these needs can then be linked to specific design requirements, such as the use of real-time tracking systems for aid delivery, the availability of reliable transportation networks, and the provision of communication devices to aid workers. Prioritizing these requirements based on their importance and criticality enables the development of effective roadmaps for the design of humanitarian logistics systems that can withstand the uncertainties and complexities inherent in the field. The 2-Tuple linguistic (2-TL) model (Herrera and Martínez, 2000) is a fuzzy logic-based approach that can be used in conjunction with QFD to help handle the uncertainties and complexities of humanitarian logistics design. In this approach, linguistic variables are used to represent uncertain or vague information in a way that is more manageable and understandable. For example, rather than using precise numerical values to represent the importance of a particular design requirement, linguistic variables such as "very important", "important", and "somewhat important" can be used.

Using the 2-TL model with QFD allows for a more flexible and adaptable approach to design (Uztürk et al., 2020; Sharma et al., 2015). It enables designers to take into account the subjective opinions and perspectives of stakeholders involved in humanitarian logistics, such as aid workers and recipients of aid, whose experiences and feedback can be difficult to quantify in precise terms. The use of linguistic variables allows for a more nuanced and context-specific understanding of the needs and requirements of the system being designed. Overall, the combination of QFD with the 2-Tuple linguistic model offers a powerful tool for designing effective and resilient humanitarian logistics systems. By enabling the prioritization of critical design requirements and the handling of uncertainty through linguistic variables, this approach helps to ensure that humanitarian logistics systems are designed to meet the needs and expectations of those who depend on them, even in the face of complex and unpredictable conditions.

1.1 Objectives

The primary objective of this paper is to propose a linguistic-based approach for designing effective humanitarian logistics systems. The paper aims to address the inherent complexity and uncertainty of humanitarian logistics by using linguistic variables to guide decision-making. The authors propose using the QFD method, specifically the House of Quality (HoQ), to establish clear relationships between the key needs of humanitarian logistics and the specific design requirements necessary to meet those needs. To handle the vagueness and ambiguity inherent in humanitarian logistics, the paper proposes using fuzzy logic-based techniques in conjunction with the 2-TL model. Ultimately, the paper seeks to contribute to the literature by providing a more effective approach to prioritizing design requirements and generating relevant strategies to ameliorate the most critical needs of humanitarian logistics systems.

To achieve these objectives, the paper provides a detailed overview of the challenges associated with designing effective humanitarian logistics systems, including the need to balance efficiency with flexibility and the difficulty of establishing clear guidelines and protocols in the face of rapidly changing conditions (Chanchaichujit et al., 2019). The paper then outlines the proposed linguistic-based design approach, which involves identifying the most critical design requirements through the use of QFD and the 2-TL model. The paper also provides a case study from Türkiye to demonstrate how the proposed approach can be applied in practice. Ultimately, the paper seeks to provide a valuable contribution to the field of humanitarian logistics by offering a more effective approach to designing systems that can adapt to the ever-changing and unpredictable nature of humanitarian crises. Here are the research questions are provided to determine the main targets of the paper:

RQ1. What are the key needs that must be addressed in the design of effective humanitarian logistics systems?

RQ2. How can the QFD method be used to establish clear relationships between the needs of humanitarian logistics and the specific requirements for designing effective systems?
RQ3. How does the linguistic-based design approach compare to other existing approaches to designing humanitarian logistics systems?

The structure of this paper consists of seven sections. The second section presents a thorough review of the existing literature related to humanitarian logistics design, QFD and the 2-TL model. In section 3, the paper proposes an approach to designing effective humanitarian logistics systems, which relies on linguistic decision-making techniques using QFD and the 2-TL model. Section 4 elaborates on the data collection process adopted in the case study, while section 5 details the step-by-step process of the case study. Finally, section 6 presents the results and ensuing discussions, and section 7 concludes the paper.

2 Literature Review

In this section, the literature related to three key areas will be presented: logistics design and QFD, humanitarian logistics design.

2.1 Logistics Design and QFD

Logistics is an essential aspect of any business operation as it plays a crucial role in the movement of goods and services from the point of origin to the final destination. Effective logistics design not only ensures timely delivery of products but also significantly impacts the sustainability of the entire supply chain. Sustainable development is a critical goal for organizations across various industries, and logistics design can be a powerful tool in achieving this objective. By optimizing logistics design, businesses can reduce their environmental impact, promote resource efficiency, and enhance economic and social sustainability.

The design of sustainable logistics systems has garnered significant interest in the literature, leading to the development of various approaches and methodologies. Supply chain modeling is a particularly compelling topic in this field, as it can be used to identify potential areas for improvement and optimize supply chain processes. Chanchaichujit et al. (2019) conducted a study that examined mathematical tools and techniques utilized in sustainable supply chain management research. Their research demonstrates the relevance of mathematical tools and techniques in sustainable logistics design, as they enable businesses to make data-driven decisions that are both economically viable and environmentally and socially responsible.

Chanchaichujit et al. (2019) also highlighted QFD methodology, Büyüközkan and Berkol (2011) proposed a comprehensive hybrid model that integrated Analytic Network Process (ANP), QFD, and Zero-One Goal Programming (ZOGP) models. This model aimed to identify the sustainability requirements of customers and design, and then determine the most efficient and suitable requirements for sustainable network design. The approach began with the identification of sustainability requirements, followed by the application of ANP and QFD to establish the relationship between those requirements.

Aside from its applications in logistics design, the QFD approach has also been utilized in logistics provider selection. Sharma et al. (2015) developed a methodology that combines QFD and Taguchi Loss Function (TLF) to select the optimal third-party logistics partner. The methodology involved deriving multiple criteria from company requirements using the HoQ, which were then used to develop service attributes for the third-party logistics partner through QFD. The relative importance of these attributes was assessed using QFD, which connects decision attributes to the decision maker's requirements. In total, 15 criteria were considered, and TLF was utilized to evaluate the performance of potential logistics partners based on these criteria. The combined use of QFD and TLF provides a powerful methodology for selecting the most suitable logistics partner based on multiple criteria and can be applied to various industries and sectors.

In recent years, the QFD approach has found further application in the logistics field, particularly in logistics strategy design (Ravichandran et al., 2021) and logistics center development projects (Korkut et al., 2021). QFD is a customer-driven methodology that focuses on understanding and prioritizing customer requirements, which can be particularly useful in logistics, where customer satisfaction is a critical factor. By using QFD to identify and prioritize customer requirements, logistics companies can design logistics strategies that meet those requirements and improve customer satisfaction (Büyüközkan et al., 2011). Similarly, QFD can be utilized in logistics center development projects to identify and prioritize the features and capabilities that are most important to customers and design logistics centers that meet those requirements (Korkut et al., 2021). The use of QFD in logistics strategy design and logistics center development projects demonstrates its versatility and effectiveness as a methodology for improving logistics operations.

2.2 Humanitarian Logistics and Design

To examine the existing literature on humanitarian logistics design, a search was conducted in the Scopus database using relevant keywords. The resulting set of articles was analyzed to identify common themes and clusters of related concepts. To facilitate this analysis, a network visualization[1] was created that highlights the most frequently occurring keywords and their relationships. This visualization can help to identify critical points and clusters of related ideas within the field of humanitarian logistics design. This could help readers understand the current state of research and identify key areas of focus within the field of humanitarian logistics design.

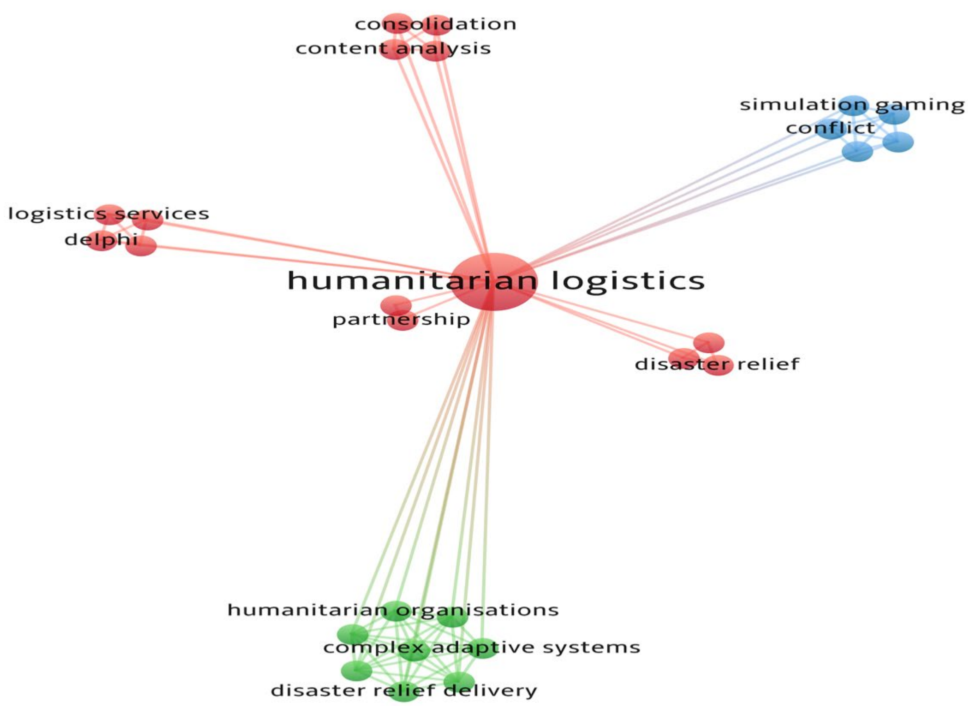


Figure 1. Network representation of keyword co-occurrences in humanitarian logistics design area.

Based on the clustering of keywords, Observations about the current state of research in humanitarian logistics design can be made (Figure 1):

- The red cluster, which includes keywords such as humanitarian logistics, partnership, disaster relief, and logistic services, suggests that there is a strong emphasis on collaboration and coordination in the design of humanitarian logistics systems. This is not surprising, as effective coordination among various stakeholders is crucial for the success of humanitarian operations (Nurmala et al., 2017; Overstreet et al., 2011; Vaillancourt, 2016; Mutebi et al., 2022).
- The green cluster, which includes keywords such as humanitarian organizations, complex adaptive systems, and disaster relief delivery, suggests that there is a growing interest in the use of complex adaptive systems theory to better understand and design humanitarian logistics systems. This approach recognizes that humanitarian logistics systems are dynamic and constantly changing, and therefore require flexible and adaptable strategies (Gossler et al., 2019; Renteria et al., 2021).

• The blue cluster, which includes keywords such as simulation gaming and conflict, suggests that there is some interest in using simulation and gaming techniques to model and test different humanitarian logistics scenarios. This

[1] VoSViewer

could be particularly useful in situations where it is difficult or impossible to conduct real-world experiments, such as in conflict zones (Lukosch et al., 2019; Overstreet et al., 2011).

Overall, the clustering of keywords suggests that there is a diverse range of approaches and perspectives being used in the study of humanitarian logistics design. By understanding these different approaches, researchers and practitioners can gain a more comprehensive understanding of the field and develop more effective strategies for designing and managing humanitarian logistics systems.

In the proposed methodology, the competencies required for successful humanitarian logistics are identified as CNs in the HoQ matrix, while the requirements for successful humanitarian logistics are defined as DRs. This study aims to use the QFD approach to establish the relationship between CNs and DRs by first deriving the must-have skills for CNs from existing literature, and then identifying the DRs from the same sources. The resulting CNs and DRs are then discussed with a decision-making group composed of logistics experts with extensive experience. More information about the decision-making group is provided in the Case Study section. Through the use of QFD, this methodology enables the identification of the most important competencies and requirements for successful humanitarian logistics, as determined by both literature review and expert opinion. Here, the CNs and DRs compiled from the literature are presented in Table 1.

Table 1. CNs and DRs of HoQ for humanitarian logistics.

Customer Needs (CNs) (Heaslip et al., 2018; Paciarotti et al., 2021; Holguín-Veras et al., 2012)	**Design Requirements (DRs)** (Fuqua et al., 2022; G. Kovács et al., 2021; Kwapong Baffoe et al., 2020; Raja Sreedharan et al., 2020)
CN1. Business Skills **CN2.** Logistic Skills **CN3.** Management Skills **CN4.** Technological Skills **CN5.** Emotional/Softer Skills **CN6.** Monitoring Skills **CN7.** Security and Safety Skills **CN8.** Awareness Skills	**DR1.** Telecommunication standards **DR2.** Packaging standardization **DR3.** Standardized kits **DR4.** Standard selection of relief goods **DR5.** Standardization for equipment **DR6.** Warehouse standardization **DR7.** Service standardization **DR8.** Human resources standardization **DR9.** Information system standardization **DR10.** Performance measurement standardization **DR11.** Process, procedures, tools, and practice standardization

3 Methods

The present section outlines the methods utilized in this research, which comprise of QFD and the 2-TL Model. Moreover, 2-TL-QFD methodology is introduced. Each methodology will be explained in detail, along with its application in this study to achieve the research objectives.

3.1 Quality Function Deployment

Shigeru Mizuno and Yoji Akao first introduced QFD at the end of 60's (Akao, 1990). Then Kiyotoka Oshiumi made the first detailed application for Bridgestone in 1966. Later in 1972, Mitsubishi Company has started to use this technique in their business. In 1984 the use of this technique spread all around the world. HoQ is the central part of QFD where CNs and DRs have evaluated in a standard matrix. QFD is a popular approach for considering CNs during the product design (Akao et al., 2003). Various studies discussed QFD and its applications in different areas. The main idea of QFD is how to balance CNs. Identifying CNs is the first step in QFD, and Analytical Hierarchy Process (AHP) is the most common way to do it. Various approaches are proposed for this step in existing literature (Ozalp et al., 2020; Büyüközkan et al., 2007; Chan et al., 2002).

A decision committee is involved in each stage of establishing the HoQ. They provide their judgments on the importance of CNs, correlations between DRs, and relationships between CNs and DRs. From this point of view, this

QFD process is a regular group decision-making practice (Osiro et al., 2018; Büyüközkan et al., 2013). Due to its closeness to the group decision-making process and its soft computing steps HoQ has chosen in this study.

Group decision making is a critical aspect of effective humanitarian logistics design. In order to design logistics systems that are effective and efficient, it is necessary to incorporate the knowledge and expertise of a variety of stakeholders (Raja Sreedharan et al., 2020; G. Kovács et al., 2021). QFD is a valuable tool for this purpose, as it enables the identification and prioritization of customer needs and requirements. By combining the input of a decision-making group with the QFD approach, it is possible to develop logistics systems that are tailored to the specific needs of humanitarian operations. This methodology ensures that the most important competencies and requirements are identified and incorporated into the design process, resulting in logistics systems that are optimized for success in challenging humanitarian environments.

3.2 2-Tuple Linguistic Model

The 2-Tuple linguistic model is a fuzzy logic-based model (Zadeh, 1965). It reduces information loss while transforming linguistic data into numerical form. The 2-Tuple fuzzy linguistic representation model makes it possible to represent linguistic information with a 2-Tuple form of *(s, α)*, where *'s'* is a linguistic label and *'α'* is a numerical value representing this symbolic translation's value (Herrera and Martínez, 2000). For the necessary and basic definitions, readers can refer to (Luis 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 (Luis 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.

The 2-TL model is particularly useful for managing the uncertainty and vagueness of information in complex decision-making problems (Luis Martínez et al., 2015). By unifying information from multiple domains within a linguistic framework, the 2-TL provides a flexible evaluation framework that allows experts to express their assessments using a range of different information sources. This approach is particularly valuable in complex, multi-dimensional problems where traditional quantitative models may be insufficient or where there is a high degree of uncertainty or subjectivity involved. In this context, the 2-TL model provides a powerful and intuitive approach that enables decision-makers to incorporate both objective and subjective criteria in a consistent and structured way (Zulueta et al., 2016; L. Martínez, 2007). Ultimately, this approach can lead to more informed and effective decision-making and can help to improve the quality of outcomes in a wide range of applications, from engineering and design to business strategy and public policy.

3.3 2-Tuple Linguistic Quality Function Deployment (2-TL-QFD)

The subsequent section outlines the computational steps involved in the proposed methodology for solving the humanitarian logistic design problem (Mei et al., 2018; Zhang et al., 2018).

Step 1: Assign the objective of the study and then define a problem related to it. Afterwards, detect the requirements for this objective and form a decision maker (DM) group to solve the problem.

Step 2: Select a linguistic comparison scale for each DM to present their own opinion about the problem. Different scales can be chosen depending upon the experience of experts in the case study.

Step 3: Determine the CNs about the problem for QFD and taking their associated levels of importance from the DM group. The importance taken from the DM group is also in a Label Set form.

Step 3.1: Make the aggregation of data which has different granularity.

Step 4: Detect DRs for QFD according to the CNs.

At this step, DRs need to be evaluated by CNs to be able to get logical relations between them during the relation matrix construction.

Step 5: Construct the relation matrix for the HoQ to determine pairwise relations between CNs and DRs. This step is to determine the level of relations between CNs and DRs. Different types of scales (as in Step 2: select a comparison scale for experts) could be used for experts to express their opinions about the degree of the relation between each CN and DR.

Step 6: Aggregate the differently scaled data gathered from DMs.

Step 6.1: Translate the linguistic label sets into 2- Tuple format. Then, they have unified under the same linguistic label set. It is better to unify them under the linguistic term set which has largest number of items (Luis Martínez et al., 2015).

Step 6.2: Aggregate the data under the same granularity.

At this step, one of the 2-Tuple aggregation operators will be used. The *Weighted Average Operator (WAO)* is preferred over the others because different experts have different weights depending on their knowledge and experience in the subject. *WAO* relation is as it is mentioned in the following relation (Luis Martínez et al., 2015):

$$\vec{x} = \left(\frac{\sum_{i=1}^{n} \Delta^{-1}(r_i, \alpha_i) \times \Delta^{-1}(w_i, \alpha_i)}{\sum_{i=1}^{n} \Delta^{-1}(w_i, \alpha_i)}\right) = \Delta\left(\frac{\sum_{i=1}^{n} \beta_i \times w_i}{\sum_{i=0}^{n} w_i}\right) \quad (3)$$

where, $(r_i, \alpha_i)$is the relative importance given for each CNs by each expert; (w_i, α_i)stands for the weights of experts and n represents the number of experts and β_i is the β values for *ith* CN's importance.

Step 7: Calculate the importance of the DRs.

At this step, the importance of CNs and their relationship with DRs will be taken into consideration to calculate the importance of DRs. The importance of a DR will be calculated with the following relation (Li, 2012):

$$(v_j, \alpha_j) = 1/m \sum_{i=1}^{m} \Delta^{-1}(r_i, \alpha_i) \times \Delta^{-1}(s_{ij}, \alpha_{ij}) \quad (4)$$

where, m stands for the number of CNs, $(v_j, \alpha_j)$is the importance of DRs as a result, $(r_i, \alpha_i)$is the weights of each CN and (s_{ij}, α_{ij})represents the values in the relationship matrix for *ith* CN and *jth* DR.

Followingly, Figure 2 summarizes the suggested methodology's framework.

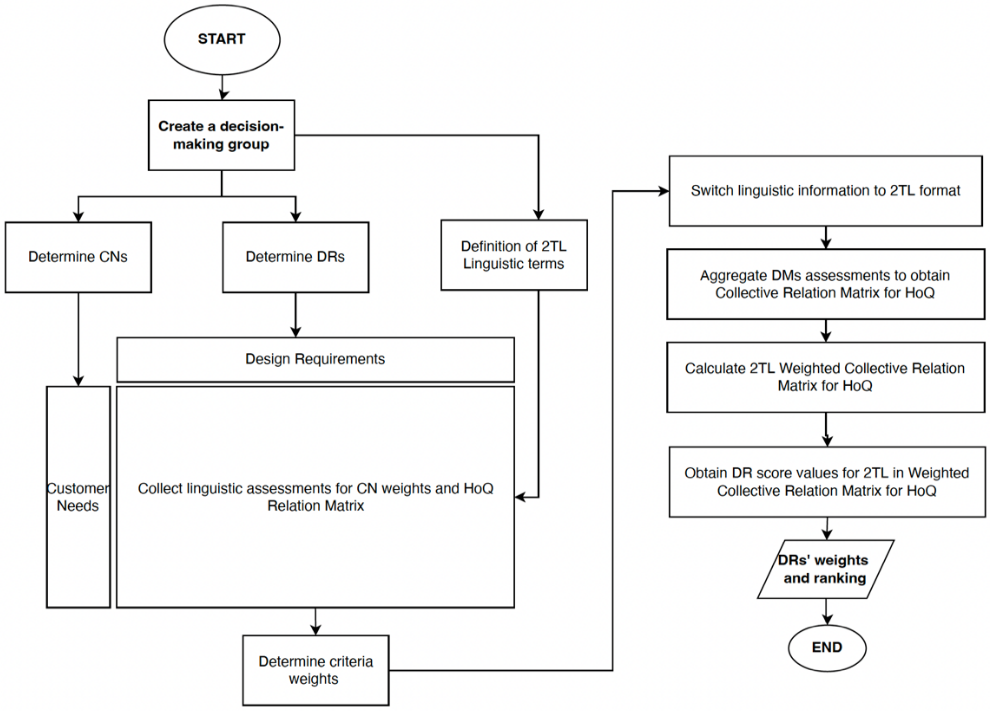


Figure 2. Suggested methodology for humanitarian logistics design.

4 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 humanitarian logistics. 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.

5 Case Study

The proposed 2-TL-QFD model is applied to the area of "Humanitarian Logistics" in Türkiye, as the country has experienced two devastating earthquakes of magnitude 7.7 and 7.6 within 8 hours. This unfortunate event highlighted the urgent need for a strategically planned humanitarian logistics system in Türkiye. The lack of readiness was attributed to the absence of standardization in emergency plans, which is a critical component of a well-designed humanitarian logistics system. As described in the previous sections, the QFD model's components were generated from the literature to address this issue. In this section, the application of the suggested model will be presented for Türkiye in detail.

The same steps provided in Section 3 are applied to the humanitarian logistics area. A decision-making group comprising three experts was formed for this case study, each of whom possesses extensive experience in the fields of logistics and humanitarian logistics. The first expert is an academician with a focus on supply chain and logistics system design, the second is a consultant with expertise in humanitarian logistics, and the third is an academician with experience in humanitarian logistics. The proposed model utilizes diverse linguistic scales to accommodate the experts' varying levels of experience. Experts who are more familiar with humanitarian logistics assess the CN-DR relationships with a nine-scaled linguistic set, while those who primarily work in supply chain and logistics systems assess these relationships with a smaller scaled linguistic set of five. The use of the 2-TL model enables multiple linguistic scales to be provided to decision-makers, thereby reducing information loss and ambiguity during the decision-making process. Here the followingly, Table 2 and Table 3 present the linguistic scales for CN assessment and CN-DR relationship definition.

Table 2. Nine scaled linguistic sets.

Linguistic Terms for CN Assessment	**Abr.**	**2-TL**	**Linguistic Terms for HoQ Matrix**	**Abr.**	**2-TL**
Absolutely Low Important	ALI	S_0^9	Absolutely Low Related	ALR	S_0^9
Very Low Important	VLI	S_1^9	Very Low Related	VLR	S_1^9
Low Important	LI	S_2^9	Low Related	LR	S_2^9
Medium Low Important	MLI	S_3^9	Medium Low Related	MLR	S_3^9
Medium Important	MI	S_4^9	Exactly Equal Related	EER	S_4^9
Medium High Important	MHI	S_5^9	Medium High Related	MHR	S_5^9
High Important	HI	S_6^9	High Related	HR	S_6^9
Very High Important	VHI	S_7^9	Very High Related	VHR	S_7^9
Absolutely High Important	AHI	S_8^9	Absolutely High Related	AHR	S_8^9

Table 3. Five scaled linguistic sets.

Linguistic Terms for CN Assessment	**Abr.**	**2-TL**	**Linguistic Terms for HoQ Matrix**	**Abr.**	**2-TL**
Very Low Important	VLI	S_0^5	Very Low Related	VLR	S_0^5
Low Important	LI	S_1^5	Low Related	LR	S_1^5
Medium Important	MI	S_2^5	Exactly Equal Related	EER	S_2^5
High Important	HI	S_3^5	High Related	HR	S_3^5
Absolutely High Important	AHI	S_4^5	Absolutely High Related	AHR	S_4^5

In order to determine the weights for each CN, each expert in the decision-making group provided their own assessments using linguistic variables to express the importance of each CN for humanitarian logistics. These individual assessments were then combined using Eq. (3) to obtain the aggregated weights. However, due to the varying levels of experience in the subject matter among the experts, different weights were assigned to each of them. Specifically, DM1, who had the most experience in the area of humanitarian logistics, was given a weight of 0.5, while DM2 and DM3, who had less experience, were given weights of 0.3 and 0.2, respectively. This approach of providing various linguistic sets and assigning different weights allowed for the more experienced assessments to be emphasized and ultimately led to the creation of an aggregated value for objective decision-making. Table 4 presents each experts assessment and their aggregated 2-TL values. Further analysis will be provided in Section 6.

Table 4. CN assessments for each DM and CNs aggregated weights for HoQ matrix.

CN#	**DM1**	**DM2**	**DM3**	**Aggregated**
CN1	MHI,0	MHI,0	HI,0	(MHI,0.20)
CN2	AHI,0	MHI,0	AHI,0	(VHI,0.10)
CN3	VHI,0	AHI,0	HI,0	(VHI,0.10)
CN4	AHI,0	AHI,0	AHI,0	(AHI,0)
CN5	HI,0	VHI,0	HI,0	(VHI, -0.20)
CN6	VHI,0	AHI,0	MI,0	(VHI, -0.30)
CN7	AHI,0	AHI,0	AHI,0	(AHI,0)

CN8	VHI,0	AHI,0	HI,0	(VHI,0.10)

After the experts' assessments of the CN weighting, they were then asked to provide their evaluations of the CN-DR relationships in the HoQ matrix. Each expert gave their own evaluation using linguistic variables to express the relationships between CNs and DRs. Similar to the CN weighting, the individual evaluations were first collected separately, and then aggregated using Eq. (3) to obtain an overall decision matrix. The aggregated matrix can be seen in Table 5. By collecting the experts' individual evaluations and combining them into a single matrix, the proposed methodology ensures that multiple viewpoints are taken into consideration for a more comprehensive and objective decision-making process.

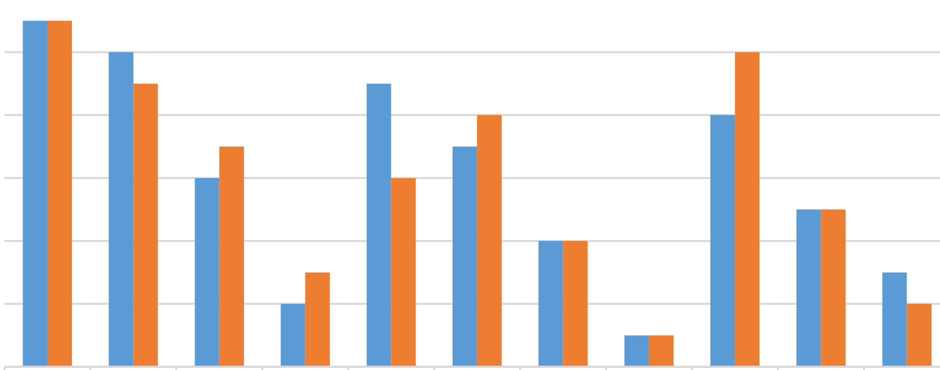
Table 5. Aggregated ultimate relation matrix for basic HoQ.

	CN Wt.	**DR1**	**DR2**	**DR3**	**DR4**	**DR5**	**DR6**	**DR7**	**DR8**	**DR9**	**DR10**	**DR11**
CN1	(MHI,0.20)	(HR,0)	(HR, -0.30)	(HR,0)	(HR,0)	(HR, -0.30)	(HR,0)	(HR,0)	(HR,0.30)	(HR,0)	(HR,0)	(HR,0)
CN2	(VHI,0.10)	(VHR,0)	(VHR,0)	(VHR,0.30)	(VHR,0)	(VHR,0)	(AHR,0)	(VHR,0)	(VHR,0.30)	(VHR,0)	(VHR,0)	(AHR,0)
CN3	(VHI,0.10)	(HR,0)	(HR,0)	(HR,0)	(HR,0)	(HR,0.30)	(HR,0)	(HR,0)	(HR,0)	(HR,0)	(VHR, -0.40)	(HR,0)
CN4	(AHI,0)	(AHR,0)	(AHR, -0.30)	(AHR, -0.30)	(AHR,0)	(AHR,0)	(AHR,0)	(AHR,0)	(AHR,0)	(AHR,0)	(AHR,0)	(AHR,0)
CN5	(VHI, -0.20)	(LR,0)	(MLR, -0.40)	(LR,0.30)	(AHR,0)	(LR,0)	(LR,0)	(MLR,0)	(VHR, -0.40)	(LR,0)	(MLR,0)	(HR, -0.10)
CN6	(VHI, -0.30)	(MLR,0)	(MLR,0)	(MLR,0.30)	(EER,0)	(MLR,0)	(MLR,0)	(VHR,0)	(VHR,0)	(HR,0)	(AHR,0)	(AHR,0)
CN7	(AHI,0)	(VHR,0)	(VHR,0)	(VHR,0)	(AHR,0)	(VHR,0.30)	(VHR,0)	(VHR,0)	(AHR,0)	(VHR,0)	(VHR,0.30)	(VHR,0)
CN8	(VHI,0.10)	(LR,0)	(MLR, -0.40)	(HR,0)	(AHR,0)	(LR,0.30)	(EER,0)	(EER,0)	(AHR,0)	(LR,0)	(LR,0)	(LR,0)

In accordance with Step 7 outlined in the previous section, the DR weights can be determined using the aggregated matrix. The subsequent section will provide a detailed analysis of the results, including a sensitivity analysis and a comparative study.

6 Results and Discussion

In this section, the results of the case study and further analysis are presented. A comparative analysis is conducted to compare the implications of ordinary QFD with the 2-TL-QFD results. The findings of this analysis are then discussed. Additionally, a sensitivity analysis is carried out to test the robustness and sensitivity of the proposed methodology under different CN weight conditions. The results of this analysis are presented and discussed in detail. Overall, the findings provide valuable insights into the effectiveness and applicability of the proposed 2-TL-QFD methodology in the context of humanitarian logistics. Here Figure 3 gives the comparative results.



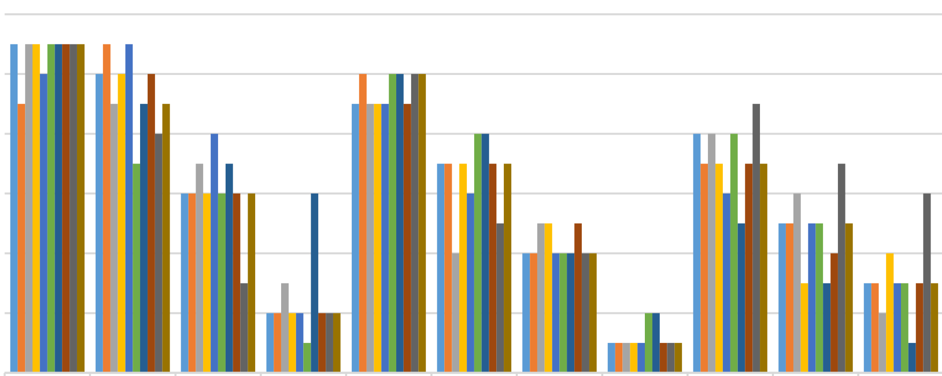
	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	DR9	DR10	DR11
2-TL QFD	11	10	6	2	9	7	4	1	8	5	3
ORDINARY QFD	11	9	7	3	6	8	4	1	10	5	2

Figure 3. Comparative analysis.

Comparing the rankings obtained from the ordinary QFD and the 2-TL-QFD methodology reveals that they are mostly similar, but with some differences in certain DRs. This indicates that the proposed methodology is reliable and can produce results that are consistent with the well-established ordinary QFD. However, it is important to note that the nature of linguistic decision-making can introduce some variations in the rankings due to the inherent ambiguity in the process. Although these differences may not be significant for small-scale applications, they can have more significant consequences for strategic decision-making and planning. Therefore, it is crucial to thoroughly examine and interpret the rankings, taking into account the possible variations and their potential impact on the decision-making process.

Upon examining the rankings, DR8, DR11, DR4, DR7, and DR10 are identified as the most critical design criteria. According to the existing literature on humanitarian logistics, the DRs between 1 to 6 are mainly related to the Physical Requirements, while the DRs between 7 to 14 cover the organizational requirements. Comparing these two groups, it is evident that most design requirements in the case study are related to organizational requirements. This suggests that addressing organizational skills and organizational design requirements is crucial to achieving successful humanitarian logistics for future disasters in Türkiye.

It is important to note that this case study's results may differ based on the country, culture, or experience of the experts on the subject. However, the study's findings are based on the input of experienced experts in the field. To further validate the model, a sensitivity analysis is conducted to confirm its robustness and consistency under different criteria weights. Overall, the findings presented in this section provide valuable insights into the effectiveness and applicability of the proposed 2-TL-QFD methodology in the context of humanitarian logistics. The results of the sensitivity analysis further demonstrate the model's consistency and robustness under changing criteria weights. Here Figure 4 gives the sensitivity analysis.



	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	DR9	DR10	DR11
Case Study	11	10	6	2	9	7	4	1	8	5	3
Case 1	9	11	6	2	10	7	4	1	7	5	3
Case 2	11	9	7	3	9	4	5	1	8	6	2
Case 3	11	10	6	2	9	7	5	1	7	3	4
Case 4	10	11	8	2	9	6	4	1	6	5	3
Case 5	11	7	6	1	10	8	4	2	8	5	3
Case 6	11	9	7	6	10	8	4	2	5	3	1
Case 7	11	10	6	2	9	7	5	1	7	4	3
Case 8	11	8	3	2	10	5	4	1	9	7	6
Case 11 (Equal Weight)	11	9	6	2	10	7	4	1	7	5	3

Figure 4. Sensitivity analysis.

Upon examining the results of the sensitivity analysis, it appears that there are no significant changes in the DR rankings when the CN weights are altered. This suggests that the proposed model is robust and can perform consistently under different conditions. These findings provide further support for the validity and reliability of the proposed 2-TL-QFD methodology for humanitarian logistics design.

DR8, which pertains to "human resource standardization," consistently ranked first or second place in the sensitivity analysis under different CN weights. This implies that developing strategies to address human resource standardization is crucial for effective humanitarian logistics planning, particularly in Türkiye where organizational requirements are deemed more critical than physical requirements. Furthermore, DR4, which pertains to "standard selection of relief goods," ranked in the top three in the overall ranking but dropped to sixth place in Case 6 where monitoring skills were deemed most critical. This can be attributed to the low relationship between CN6 and DR4. By analyzing the effect of each CN on the DR ranking, the sensitivity analysis provides valuable insights into which criteria should be prioritized when developing strategies. Overall, the findings suggest that prioritizing "Human Resources" is crucial when generating strategies for humanitarian logistics in Türkiye. According to the results some strategies are developed with the decision-making group and the existing literature on humanitarian logistics (de Camargo Fiorini et al., 2022; Paciarotti et al., 2021; Schiffling et al., 2022) .

1. Develop a standardized training program: Create a training program that covers all aspects of humanitarian logistics and standardize the training provided to all the staff involved in humanitarian logistics operations.
2. Establish job descriptions: Develop and document clear job descriptions for all the roles involved in humanitarian logistics operations. This will ensure that all the staff are aware of their roles and responsibilities.
3. Implement performance metrics: Set performance metrics that can be used to evaluate the effectiveness of the humanitarian logistics operations. This will help identify areas that require improvement.
4. Create a central database: Establish a centralized database of qualified personnel and their skills. This will help ensure that the right personnel are deployed to the right tasks.
5. Provide incentives: Develop incentives for staff to encourage them to achieve higher levels of qualification in humanitarian logistics. This will help ensure that the staff are motivated to continue developing their skills.
6. Foster collaboration: Foster collaboration among the different stakeholders involved in humanitarian logistics, including government agencies, NGOs, and private organizations. This will help ensure that there is a standardized approach to humanitarian logistics across all organizations.

7 Conclusions

In conclusion, this study has proposed a 2-TL model based QFD methodology for designing effective humanitarian logistics. The motivation for this research was the recent earthquake in Türkiye which highlighted the country's unpreparedness in terms of organizational and physical requirements. By utilizing the proposed model, practitioners can identify their strengths and weaknesses and create a roadmap for designing their humanitarian logistics according to the DR rankings.

The contribution of this study lies in its fuzzy logic-based linguistic computational steps and its adaptation of the QFD methodology for humanitarian logistics design. While the number of experts in the study may be limited, the analysis showed the validity of the methodology for small-scale applications. Future studies can involve larger decision-making groups and compare the results of different applications. Moreover, for future studies the prioritization of the strategies proposed in the previous section can be analyzed and assessed using novel MCDM techniques.

Through literature review and expert meetings, this study has revealed a design model that emphasizes the basic requirements for successful humanitarian logistics design. Overall, the research questions posed in the first section have been answered by the case study and model construction, demonstrating the applicability of linguistic decision-making and QFD for humanitarian logistics design. This study contributes to the literature in the field of humanitarian logistics and can serve as a starting point for further research and practical implementations.

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Biographies

Gülçin Büyüközkan is the Dean of the Engineering Faculty, Galatasaray University, Türkiye. She also works as a professor in the Industrial Engineering Department of the same university. Her current studies mainly focus on smart systems, smart technologies, digital transformation, sustainability, supply chain management, multi-criteria decision making, and the application of intelligent techniques on these areas. Prof. Büyüközkan is the author of numerous journal and conference papers.

Deniz Uztürk is a Ph.D. student in industrial engineering and a research assistant in the Management Department on Numerical Methods area at Galatasaray University, Türkiye. She holds her Master of Science in Industrial Engineering in which she worked on the sustainable building design. Her research areas are smart technologies, multi-criteria decision making, fuzzy logic and its applications.