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Identification of Key Drivers for Performance Measurement in Sustainable Humanitarian Relief Logistics: An Integrated Fuzzy Delphi-DEMATEL Approach

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Abstract: Sustainable humanitarian relief logistics (SHRL) is gaining attention due to increased disasters, unpredictable demand, large volumes, high delivery stakes, and limited resources, evaluated through adaptable performance drivers. This study presents a novel hybrid framework for SHRL, combining the Fuzzy Delphi Method (FDM) and Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL). Initially, FDM is utilized to reach a consensus among experts concerning key performance indicators (KPIs) for humanitarian logistics and supply chains. By incorporating the inherent uncertainty and vagueness in expert judgments, FDM refines the list of key performance indicators that reflect the real-life conditions and constraints in disaster operations. Finally, the fuzzy DEMATEL approach was used to analyze the interrelationships among factors, identifying cause-and-effect behavior and ranking them, forming a robust theoretical framework. Based on the acquired results, the KPIs attached to the Quality (P1) aspect of the proposed framework have gained significant importance and are the main cause in a cause-and-effect relationship which impacts and is helpful to improve the performance of humanitarian organizations in all phases of disaster management. The KPIs prompt delivery (D1), and delivery accuracy (D2) are more significant, while capacity building and training (D19) and delivery compliance (D15) are least significant in SHRL scenarios. This research is expected to support humanitarian organizations in enhancing their capabilities, thereby improving the effectiveness and efficiency of aid delivery in disaster-stricken areas.

Keywords: humanitarian relief logistics; drivers; performance measurement; fuzzy Delphi; fuzzy DEMATEL; sustainable development

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1. Introduction

In the last few decades, there has been an enormous increase in the frequency of natural disasters [1]. Reviewing records on natural disasters indicates a growing trend in large-scale calamities such as floods, droughts, hurricanes, earthquakes, glacier melting, and various others [2]. According to data from the Centre for Research on the Epidemiology of Disasters [2], from 2000 to 2022, 3852 floods, 282 wildfires, and 2401 storm events occurred. Some major disasters, such as California experiencing significant wildfires in 2023, including the largest in state history, the Mosquito Fire, which destroyed over 300,000 acres and caused billions of dollars in damage. The Hunga Tonga–Hunga Ha'apai volcano eruption in January 2022 caused a devastating tsunami, while major hurricanes like Ida, Typhoon Goni, and Cyclone Idai caused widespread destruction [2]. Disasters have a profound impact on people's lives as well as the economy and environment. Table 1 vividly portrays a discernible increase in disaster trends, highlighting escalating patterns and changes in the data of the Emergency Events Database (EM-DAT) from 2000 to 2022 [2]. The escalating influence of disasters, specifically, the number of occurrences, fatalities, and financial, and ecological damages, highlights the importance of preemptive and proactive strategies, effective disaster management, and efficient humanitarian relief logistics in disaster preparedness, response, and mitigation.

Table 1. Emergency Events Database (EM-DAT) from 2000 to 2022 [2].

Disaster Type	No. of Events	Total Deaths	Total Affected Population	Total Damages, Adjusted (Million USD)
Flood	3852	122,936	1,767,571,036	914.07
Wildfire	282	1789	14,624,031	130.24
ExtremeTemp.	479	235,480	96,496,219	69.29
Storm	2401	204,973	801,550,134	1981.30
Earthquake	626	725,678	125,077,715	815.79
Drought	390	23,892	1,629,767,593	210.47

Humanitarian logistics is the brain of humanitarian relief operations. Furthermore, humanitarian logistics encompasses the strategic organization and management of various activities, such as planning, procurement, transportation, inventory pre-positioning, distribution, and ensuring recipient satisfaction [3,4]. HRL is gaining attention from researchers, academics, and practitioners due to the need for agile systems, better coordination, flexibility, accountability, specialized risk management, and the impact of disasters on human lives and economies [5–7]. Furthermore, projections indicate that the frequency of both natural and man-made disasters will experience a fivefold rise within the next 50 years [2,3]. Consequently, humanitarian logistics holds significant importance within disaster management systems. Van Wassenhove [4] argued that eighty percent of the total relief cost is for humanitarian logistics alone, which highlights its importance. In the literature, the terms "humanitarian logistics", "relief logistics", and "humanitarian supply chain" are frequently used interchangeably [8]. Humanitarian Relief Logistics (HRL) plays a vital role in disaster management [9,10]. It also helps humanitarian organizations to achieve their goals. HRL faces challenges in achieving its mission while minimizing environmental impact, managing resources effectively, and ensuring social responsibility.

The increasing awareness of environmental and social sustainability issues and their integration into supply chain management contributes to competitiveness. In the commercial sector, sustainability has been identified as a significant business opportunity for the last few decades. In the future, both commercial and humanitarian supply chains will be guided by sustainable development and ecological balance [9]. The focus on sustainability promotes long-term resilience and environmental responsibility, despite challenges in short-lived crises, and there is a growing demand for its integration into humanitarian logistics and supply chains [11,12]. This study suggests that sustainability parameters are not adequately considered in measuring the performance of HRL [13]. Decision makers in the humanitarian sector need to evaluate their decisions' impact on sustainability performance objectives to improve processes and anticipate future impacts. However, the sector's recent incorporation of sustainability in management lacks concrete metrics and tools for measuring performance [14]. Multiple authors have advocated for further investigation to incorporate sustainability into the decision-making process related to humanitarian relief logistics [12,14–16]. To address this gap, this study also highlights the recent inclusion of sustainability in management and the lack of concrete metrics for measuring performance in HRL. It also proposes a set of sustainability performance measures and associated metrics.

Humanitarian logistics plays a crucial role in humanitarian relief operations, involving the strategic organization and management of various activities, including planning, procurement, transportation, inventory pre-positioning, distribution, and ensuring recipient satisfaction [3,4]. Moreover, projections indicate that the frequency of both natural and man-made disasters will experience a fivefold rise within the next 50 years [2,3]. Consequently, humanitarian logistics holds significant importance within disaster management systems. Van Wassenhove [4] argued that eighty percent of the total relief cost is for humanitarian logistics alone, which highlights its importance. The rise in natural disasters places a burden on humanitarian organizations (HOs) to provide humanitarian assistance in a suitable and cost-efficient manner [4,17,18].

Blecken [19] revealed that 55% of humanitarian organizations lack performance measurement indicators, 25% use a few, and only 20% consistently measure performance. Moreover, research indicates that humanitarian logistics employs commercial logistics strategies, including inventory management, location of logistics, and emergency centers [20], and routing for aid distribution and evacuation [21]. The integration of commercial logistics performance measurement metrics cannot be fully replicated in HRL due to the intrinsic attributes of humanitarian relief operations [22]. Abidi and Hella [23] emphasized that the difficulty in evaluating performance in humanitarian operations arises from a lack of alignment between short-term goals and overarching long-term strategic objectives. Usually, evaluating and improving the performance of HRL involves considering traditional KPIs such as cost, quality, time, responsiveness, reliability, and process flexibility [6,24]. Furthermore, sustainability aspects, which encompass economic, environmental, and social factors, are integral to the triple bottom line.

Performance measurement is crucial for efficient and effective humanitarian logistics activities, as it quantifies the efficiency and effectiveness of operations using indicators to measure the central goals of firms or organizations. Performance measurement informs decision makers at strategic, tactical, and operational levels, and is crucial for implementing and realizing strategic goals. It facilitates effective control and correction by reporting current performance levels and comparing them with desired levels. It is fundamental for inducing improvement, informing decision making, simplifying communication between actors, and increasing transparency. It also helps identify success, customer needs, problems, and bottlenecks, track progress, and facilitate open and transparent communication. Measuring actual performance in humanitarian relief activities is crucial to identifying an HO's target for achieving objectives. Unfortunately, the performance measurement system for HRL has not been adequately handled [25,26]. Thus far, the measurement of HRL performance in HOs has not been systematically planned and performed, unlike in commercial organizations [27].

To cover this gap, researchers are working on a performance measurement framework in HRL [8,17,20,28,29]. Some researchers have adopted commercial supply chain performance frameworks in HSC, such as the Supply Chain Operations Reference (SCOR) Model and the balanced scorecard (BSC) [21,24,30,31]. The SCOR model has limitations such as complexity, resource requirements, lack of flexibility, potential neglect of sustainability, and reliance on inaccurate data [32], while the BSC has been criticized by authors for its structural shortcomings [33]. Decision makers face uncertainty when it comes to choosing and ranking performance indicators [33]. Some researchers argued that insufficient understanding of priorities and misclassification of KPIs can result in inefficient execution, hindering the development of accurate and impactful PMS [31,34]. Thus, choosing specific KPIs from several options is a complicated and subjective task, requiring a methodical strategy to establish their weights, ranking, grouping, and relative significance [35]. KPIs play a crucial role in ensuring the efficient and effective management of HRL. HOs encounter difficulties in establishing KPIs because of the wide-ranging and complex nature of their activities and the different requirements of the stakeholders [14,26].

Various multi-criteria decision-making (MCDM) techniques for selecting and prioritizing KPIs have been documented in the academic literature, such as the technique for order preference by similarity to ideal solution (TOPSIS) [36], analytical hierarchy process (AHP) [37], VIsekriterijumska optimizacija i KOmpromisno Resenje (VIKOR), and analytical network process (ANP). The question arises: what methodology is adopted in our study to identify key drivers for performance measurement in SHRL? TOPSIS is a logical approach to ranking alternatives based on distance from the ideal solution, assuming criteria independence and not handling uncertainty inherently [38]. The AHP hierarchy evaluates the distribution of a goal among compared elements and determines which element has a greater influence on that goal, assuming the absence of interdependence between criteria and the lack of inherent management of uncertainty [38,39]. The VIKOR technique utilizes a ranking index that is based on a specific measure of "closeness" to the ideal solution using linear normalization. ANP is characterized by its time-consuming nature, complexity, and subjectivity, which adds to the difficulty of defining goals and criteria [40]. The DEMATEL methodology offers some advantages in comparison to existing MCDM methods as the DEMATEL tool effectively analyzes mutual influences among factors and understands complex cause-effect relationships in decision-making problems. It visualizes interrelationships via an influential relationship matrix, ranks alternatives, and determines critical evaluation criteria and weights. Although AHP is valuable for prioritizing options and establishing the importance of criteria, it operates under the assumption that criteria are autonomous and neglects to account for their interrelationships and interdependencies [41,42]. The ANP can manage criteria dependence; however, the assumption of equal weight for each cluster in a weighted supermatrix is not feasible in real-life scenarios [40–42].

In a nutshell, thus far, HRL managers have aimed to enhance competitiveness by efficiently managing supply flows and minimizing costs [14]. Following the continuing development of the sustainability paradigm, it is necessary to incorporate social, economic, and environmental performance indicators into the performance measurement model of HRL [43]. Considering this requirement, the scholarly literature has recognized a deficiency that necessitates the development of a comprehensive framework for establishing KPIs in the realm of SHRL [11]. As HRL is quite a young field, very little work is available in this context in first-quartile journals [44]. MCDM techniques are used by very few authors; Anjomshoae and Ali [33] conducted a ranking analysis of hierarchically organized key performance indicators in the HSC using Analytic Hierarchy Process (AHP) analysis, and highlighted the importance of the performance measurement system in relief chains [33]. Yadav and Barve [45] propose a network framework for different disaster preparedness activities and prioritize these actions using fuzzy ANP. Venkatesh and Zhang [39] developed a framework for partner selection problems in continuous aid HSC operations using a fuzzy AHP-TOPSIS approach. Due to the complexity, domain specificity, and subjectivity of the process of selecting and categorizing KPIs, a methodical framework is required.

There has been no previous research that has identified and prioritized KPIs that support SHRL concerning the quality, accountability, and triple bottom line (TBL) dimensions of sustainability. Furthermore, a comprehensive modeling technique that incorporates Fuzzy Delphi–DEMATEL is utilized.

This approach allows for the grouping and prioritization of aspects, which are then incorporated into a robust framework. It is important to mention that prior to this study, no other research has utilized this integrated methodology in SHRL to uncover the main drivers for measuring performance. This methodology incorporates both qualitative and quantitative data collection methodologies. The major problem is the identification of key performance indicators in humanitarian relief logistics, incorporating sustainability, quality measures, and accountability. Based on that, the proposed study aims to address the following further research questions:

- Which KPIs of the performance measurement model are utilized in SHRL?
- How can SHRL KPIs be assessed under data uncertainty?
- How does the integration of the fuzzy Delphi-DEMATEL method enhance the accuracy and reliability of performance measurement in SHRL?

To summarize, the primary research contributions from both the modeling and the literature aspects of this study are as follows:

- The study identified KPIs in sustainable humanitarian relief logistics by examining economic, social, and environmental sustainability indicators, as well as quality and accountability measures, through an extensive literature review. This topic had limited or no previous research available. It offers an understanding of operational, strategic, and tactical efficiency, efficacy, and sustainable development in humanitarian environments.

- This study utilizes fuzzy Delphi methodology to experimentally test the suggested KPIs in real-world settings, with the collaboration of humanitarian practitioners, media personalities, and academic researchers. Fuzzy Delphi is effective for categorizing KPIs in the presence of uncertainty. It assists in determining the presence of these KPIs in SHRL.
- A strong framework was developed in this study by employing a fuzzy DEMATEL approach to prioritize the identified KPIs using fuzzy Delphi. The primary benefit of fuzzy DEMATEL is its ability to successfully analyze qualitative and quantitative KPIs in the presence of data uncertainty. The fuzzy DEMATEL technique analyzes the cause-and-effect behavior and identifies the interdependent relationships among KPIs.

The following parts of the paper are organized as follows: the second part of the paper provides a clear and detailed explanation of the literature review. The third section offers a comprehensive examination of the research methodology. The fourth section outlines the main findings of the proposed study. The fifth segment is dedicated to examining the consequences or ramifications of the topic, while the last section serves as the ultimate summary or resolution.

2. Literature Review

This section discusses the concept of sustainable humanitarian relief logistics and performance measurement. Furthermore, this section presents the identification of KPIs based on a comprehensive literature review. Finally, the detailed literature regarding the use of Fuzzy Delphi-DEMATEL has been provided comprehensively.

2.1. Contextualization of Sustainable Humanitarian Relief Logistics

The concept of sustainability in humanitarian logistics has gained significant attention in recent years as humanitarian organizations strive to deliver aid effectively while minimizing negative environmental and social impacts [16]. SHRL is a young field compared to commercial sustainable logistics; due to the growing trend of disasters in the last few decades, researchers and academicians are paying attention to this field. Before contextualizing SHRL in detail, disaster, humanitarian logistics, relief activities, and sustainability are described and categorized precisely. The word "disaster" evokes thoughts of unpredictable destruction and devastation [46]. Disasters, whether natural or man-made, have a significant impact on society, the environment, and individuals [4,47]. In the past few decades, there has been an increasing trend in these incidents [1,2]. The United Nations Office for Disaster Risk Reduction [48], and the International Federation of Red Cross and Red Crescent Societies [49] define a disaster as follows: "Disasters are serious disruptions to the functioning of a community that exceeds its capacity to cope using its own resources. Disasters can be caused by natural, man-made, and technological hazards, as well as various factors that influence the exposure and vulnerability of a community".

Disasters, both natural and man-made, cause significant human, material, economic, and environmental losses, and their severity depends on factors like environmental stability, hazard threats, and population vulnerability [48]. Disaster relief and continuous aid activities fall under the category of disasters in the context of humanitarian relief [17,50]. Disaster relief involves providing aid in response to natural disasters, while continuous aid activities encompass aid for developing regions or refugee camps [17].

Effective disaster management is crucial to mitigate these impacts. Van Wassenhove [4] argued that effective disaster management involves preparedness and response, including human resource selection, knowledge management, operations preparation, financial resource preparation, and collaboration actions. The response relies on preparedness, local conditions, migration activities, and rehabilitation after disaster relief, encompassing core phases. Kovács and Spens [17] define humanitarian logistics as "right people, equipment and material, in the right place, in the right sequence as soon as possible, to deliver the maximum relief at the least cost—saved lives, reduced suffering and the best use of donated funds". The Fritz Institute [3] also defines humanitarian logistics as "the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption to alleviate the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking, tracing, and customs clearance". Therefore, examining the definition of sustainability, logistics, and humanitarian logistics helps us to better understand the context.

The contextualization of sustainable humanitarian relief logistics involves activities not only to save humanity with short-term goals but also long-term goals based on the basic principle of sustainability: "do no harm". However, the Brundtland Commission's definition of sustainability emphasizes meeting current needs without compromising future generations' ability to meet their own [3]. The conceptualization of sustainability in the context of humanitarian logistics and supply chains is crucial. Robert Engelmen [51] highlights the complexity of sustainability in our current age, encompassing various meanings from environmental improvement to cooling. Sakalasooriya [52] defines sustainability as the equitable, ethical, and efficient use of natural resources to meet the needs of current and future generations while enhancing their well-being. Al-Abbadi and Abu Rumman [53] argue that sustainability refers to an organization's capacity to achieve its business goals and enhance shareholder value by addressing its long-term economic, environmental, and social responsibility. Pojasek's definition of sustainability outlines an organization's ability to effectively manage environmental stewardship, social well-being, and economic prosperity while maintaining accountability to stakeholders [54,55]. We are going to adopt the definitions stated by Al-Abbadi and Abu Rumman [53] and Pojasek [55] as most relevant in our research context. Sustainable logistics includes the enhancement of supply chain operations, which encompass the procurement of raw materials, their conversion, storage, packaging, distribution, and the management of products at the end of their lifecycle. Figure 1 shows the interconnection of disaster management, humanitarian logistics, and sustainability. It illustrates the integration of these three domains to form SHRL. This study focuses on examining how incorporating these interconnected KPIs can help HOs efficiently provide assistance and promote sustainable development in disaster-affected areas.

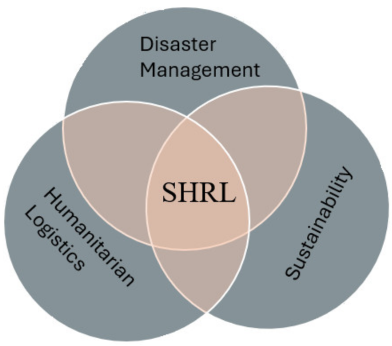

Figure 1. Description of Sustainable Humanitarian Relief Logistics.

Haavisto and Kovács explore sustainability's impact on humanitarian supply chain performance, highlighting its importance alongside efficiency [15]. However, the long-term adverse effects of cost-oriented HL are significant, prompting further research on sustainable supply chain development. Hamdan and Cheaitou propose a tool for supplier selection and order allocation, integrating green criteria and shortage accounting [56]. The tool uses the TOPSIS method, AHP, and multiplication products to maximize preferences and minimize costs. Cao et al. and Zhang et al. propose multi-objective nonlinear formulations for disaster operations, focusing on equity and service satisfaction, and environmental considerations in a multi-depot routing model for emergency facilities under uncertain information [57,58]. Dubey and Gunasekaran highlighted the importance of a sustainable humanitarian supply chain, emphasizing agility, adaptability, and alignment [9]. Kempen et al. highlighted the underdevelopment of the triple-bottom-line concept in humanitarian aid [59].

Kovács and Spens established the foundation of humanitarian logistics research, highlighting the need to integrate sustainability considerations into logistical activities during disaster relief operations [7]. Jahre et al. [60] further explored the balance between efficiency and sustainability, emphasizing the need for a strategic approach in humanitarian operations, where performance is not solely measured by immediate response times but also by long-term sustainable impact.

All the discussion needs to focus on and demand new key performance indicators in the context of humanitarian relief logistics and support sustainable practices. Sustainability is the key drivers for measuring the performance of humanitarian organizations in the broader view of disaster management and relief activities to keep in mind the quality guaranteed at that time when all the stakeholders are satisfied with the measures taken by decision-makers in a transparent way. Figure 2 illustrates the stakeholders identified in earlier studies.

Figure 2. Categories of Humanitarian Organization.

2.2. *Performance Measurement in SHRL*

Performance measurement is crucial for improving humanitarian logistics operations, but its development and systematic implementation in the relief chain are not widely recognized [61]. It is also worth mentioning here that the terms logistics and supply chain are used interchangeably in the context of humanitarian operations. Anjomshoae and Banomyong discussed in their literature review that not much research has been conducted on measuring SHSCM performance yet [11]. Abidi et al.'s literature review and D'Haene et al.'s case studies highlight the lack of empirical testing for performance frameworks in humanitarian logistics, highlighting the need for further research [25,62]. Furthermore, the nonprofit sector encounters difficulties in assessing performance due to the presence of many objectives [63,64] and the distinctive characteristics of the disaster relief environment, including the involvement of several stakeholders and the challenges associated with collecting data on the ground [65]. Lu, Goh, et al. [30] developed a performance measurement framework for humanitarian logistics using the supply chain operations reference (SCOR) model, following recommendations from Tatham and Spens [66] and Abidi et al. [67]. Few studies have explored strategic performance measurement concepts like the balanced scorecard for assessing the sustainability and efficiency of humanitarian operations [13,68], while Laguna-Salvadzo et al. [14] developed a multi-objective master planning decision support system for performance management of SHSCM. The performance measurement framework on SHRL is scarce, especially to link quality and accountability with sustainable measures of humanitarian logistics. The study identifies KPIs in sustainable humanitarian relief logistics by examining economic, social, and environmental sustainability indicators, quality, and accountability measures. It uses the fuzzy Delphi methodology to test these KPIs in real-world settings, collaborating with humanitarian practitioners, media personalities, and academic researchers. The fuzzy DEMATEL approach is used to prioritize the KPIs, analyzing qualitative and quantitative KPIs in the presence of data uncertainty. This approach helps determine the presence of KPIs in humanitarian relief logistics and identifies interdependent relationships among them. The need for a robust performance measurement framework underscores the importance of setting goals to achieve sustainability and satisfying the various humanitarian actors in the field of humanitarian logistics.

In a nutshell, Tatham and Hughes [69] argue that humanitarian organizations (HOs) lack a widely used performance measurement framework, while studies by Lu, Goh et al. [30] and Laguna-Salvadzo et al. [14] highlight the lack of a well-established performance measurement framework, especially when compared to the commercial sector. Existing measures for improving HO relief operations are results-based, causing uncertainty due to factors beyond one organization's control. Abidi et al. [67] suggest a process-based performance measurement framework and KPIs to address these challenges. Blecken's model, which uses supply chain process modeling to measure HO performance, is limited to strategic levels and lacks sufficient KPIs to measure performance attributes like reliability and cost across multiple chain levels [19]. Lu, Goh, et al. proposed a performance measurement framework using the SCOR model, a comprehensive supply chain process model with pre-made KPIs for the commercial world [30]. Guhathakurta [32] and Davidson [35] have both criticized the SCOR for its inflexibility, limited scope, and rigidness in evaluating performance in humanitarian logistics.

Davidson [35] and Beamon and Balcik [70] proposed performance indicators for humanitarian supply chains, but none have been empirically validated. D'Haene et al. found that most existing frameworks are not well-received, and data gathering is challenging for HROs [62]. Performance measurement in the humanitarian field is less developed than in the commercial world, and there is no universally accepted framework for HROs. Current measures are results-based, which may not be helpful in improving relief operations due to uncertainty. The literature calls for a process-based performance measurement framework and KPIs to reduce bias and improve supply chain operations. The SCOR model, a comprehensive supply chain process model, is proposed as the key framework, covering multiple levels of operations and providing ready-made KPIs. This aligns with the suggestion of a unified reference source for HROs.

2.3. Significant Key Performance Indicators

Performance measurement is a crucial management tool for assessing work impact, demonstrating value, managing resources, and directing efforts toward improvement. Lambert suggests aligning metrics with organizational goals for optimal performance measurement [71]. Metrics are essential for operational excellence, and success, providing objective performance measures for programs, activities, systems, and equipment. KPIs are metrics used to measure performance toward the strategic and operational objectives of organizations. They define effectiveness, monitor operational excellence, and show progress. Processes for actions in response to KPIs should be established, ensuring accurate performance and corrective action in case of discrepancies. However, implementing a performance measurement system for HOs should prioritize KPIs and define metrics that support these priorities, providing a template for delivering goods in disaster relief environments [35]. Finding the main goals and the particular requirements for the successful functioning of the organization is essential before moving further. It is well known that performance measurement can help to enhance and correct noted deficiencies in humanitarian logistics.

Recent studies of performance indicators in humanitarian relief logistics pose challenges for humanitarian organizations due to complexity and information overload, necessitating a systematic guideline for prioritizing KPIs, as existing studies lack critical analysis and judgment biases. Many authors argued that HRL faces challenges due to unpredictable demand, sudden occurrence, high stakes in delivery timeliness, and resource scarcity [7]. HOs make sure that relief gets to afflicted places promptly and precisely, attending to the requirements of the afflicted people and averting more problems. The survival rate and recovery process are significantly impacted by the speed and accuracy with which aid is provided [5,7,72,73]. So, to overcome this gap, prompt delivery, delivery accuracy, trustworthiness of delivery, responsive delivery, satisfactory delivery, delivery grievances, and delivery errors are significant KPIs that can lessen these worries. Moreover, most researchers discuss that relief operations are not transparent, which will cause a trust deficit in companies [74]; this also creates a crisis in disaster-prone areas. Compared to commercial logistics, one of the KPIs affecting public loyalty in humanitarian logistics has not garnered much attention in the literature [75]. Transparency is a growing global demand on both commercial and nongovernmental organizations [76], where all parties have been mostly concerned about corruption and poor management, especially in HL [75]. Especially during the COVID-19 pandemic, donors have been urging more openness in HL [77]. Transparency demonstrates the sincerity of the organizations in building confidence and enhancing performance by demonstrating the aim of HOs to identify honest and suitable principles related to delivery transparency, delivery participation, delivery feedback, capacity building and training, delivery compliance, and stakeholder engagement.

Furthermore, for academics and practitioners alike, sustainability is an emerging and unclear topic in HL. Among the main objectives of HL are to save lives, lessen suffering, and help to prevent disasters. Stakeholders in the business are pushing HOs to use sustainable practices since they boost income, raise employee productivity, reduce pollution, and lessen stock value volatility. To cover the shortcomings, we proposed KPIs from the environmental, social, and economic dimensions of sustainability, such as pollution control, resource conservation, local communities' empowerment, labor conditions, political instability, logistics disputes and trade disputes, legislation and regulatory amendments, minimizing total cost, and financial efficiency.

Researchers have proposed different numbers of KPIs in their research according to their specifications and research objectives. For example, Davidson [35] proposed a framework for KPIs and uses five KPIs. A total of 115 research papers on sustainable humanitarian logistics, performance measurement, relief operations, and humanitarian supply chains were examined, resulting in the identification of 25 KPIs for SHRL. The KPIs mentioned in Table 2 help to improve and monitor the performance of humanitarian organizations and enhance the generated knowledge in the field of relief operations, disaster management, humanitarian logistics, and supply chain. The selected KPIs are important in the field of humanitarian logistics and disaster management scenarios to lower the impact of disasters and also enhance the resilience of the environment.

Table 2. Significant Key Performance Indicators and Sources.

Sr No	KPIs	Sources
1	Prompt Delivery	[7,72,78]
2	Delivery Accuracy	[26,67,72,78,79]
3	Trustworthiness of delivery	[10]
4	Responsive Delivery	[79,80]
5	Satisfied Delivery	[72]
6	Delivery Grievances	[81]
7	Delivery Errors	[82]
8	Delivery transparency	[80]
9	Delivery Participation	[72]
10	Delivery Feedback	[29,34]
11	Capacity Building and Training	[83]
12	Delivery Compliance	[84]
13	Stakeholder Engagement	[85]

Table 2. *Cont.*

Sr No	KPIs	Sources
14	Resource Utilization	[73,86]
15	Impact Assessment	[73]
16	Adaptive Capacity	[86]
17	Pollution Control	[87]
18	Resource Conservation	[18]
19	Local Communities Empowerment	[88]
20	Labor Condition	[89]
21	Political instability	[90]
22	Logistics Disputes and Trade Disputes	[91]
23	Legislation and Regulatory Amendments	[92]
24	Minimize Total Cost	[72,93]
25	Financial Efficiency	[73,93]

2.4. Fuzzy Delphi-DEMATEL Methods

The Delphi method was developed by Dalky and Helmer in 1963 [94]. Many fields of research have applied the Delphi, including needs assessment, policy formulation, program planning, and resource use [95]. It has been applied in various domains, including industrial quality evaluation, investment decisions, production prediction, risk assessment and management, forecasting and trend analysis, and disaster preparedness and response [96]. However, the traditional method has deficiencies, such as low convergence rates, distorted expert opinions, and high execution costs. To address these issues, the fuzzy Delphi method was introduced by Ishikawa et al. [97]. The principles behind it were fuzzy set theory and the conventional Delphi method [98]. According to scholars and researchers, the fuzziness of common comprehension of expert perspectives can be resolved by using the FDM in group decision-making [95–99]. Researchers have improved the traditional Delphi method, including Kauko's [100] post-survey adjustment model for financial market variables, and Bouzon's [101] integration of fuzzy set theory for ambiguous decision-making. FDM has been applied in various fields such as management sciences, business management, humanitarian logistics, human–computer interaction, health-related research, and vocational training. The fuzzy Delphi method is widely utilized in management science for long-range forecasting and decision-making processes across various industries [102]. The FDM is applied in research on user experience, augmented reality, usability, mobile applications, and online learning in human–computer interaction [99]. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique and fuzzy logic are combined in the novel Fuzzy DEMATEL method to address difficult decision-making situations. By taking into account the degree of hesitation of intuitionistic fuzzy numbers, it presents fuzzy numbers to improve judgments in collective decision-making situations. Application of this approach has been made in several domains, including startup selection for acceleration programs [3,4], water security analysis [2], and manufacturing strategy formulation [1]. Fuzzy logic is used by the Fuzzy DEMATEL approach to efficiently capture the priorities and intricate relationships among the elements, which helps managers develop plans and make wise decisions in many fields.

Dealing with decision-making problems and looking for general solutions can be done practically with the FDEMATEL approach [103]. Since Gabus and Fontela [104] introduced FDEMATEL in 1972, it has been extensively used to elucidate the structural cause–effect relationships that occur in decision-making and evaluation [42,105,106]. The DEMATEL technique and fuzzy logic are combined in the novel Fuzzy DEMATEL method to address difficult decision-making situations [106]. By taking into account the degree of hesitation of intuitionistic fuzzy numbers, it presents fuzzy numbers to improve judgments in collective decision-making situations. The FDEMATEL has been applied in several domains, including startup selection for acceleration programs, water security analysis, and manufacturing strategy formulation. The FDEMATEL is used in various fields such as public opinion evaluation [107] and hospital CRM readiness [108]. Fuzzy DEMATEL is a valuable tool for analyzing factors influencing green lean supply chain management [109], improving supply chain resilience [110], and identifying barriers to sustainable supply chain management implementation in Iran [111]. Fuzzy DEMATEL helps in categorizing [112], determining causal relationships, prioritizing, and developing guidelines for logistics and supply chain operations, enhancing decision-making and system improvement [111]. Fuzzy logic is used by the Fuzzy DEMATEL approach to efficiently capture the priorities and intricate relationships among the elements, which helps managers develop plans and make wise decisions in many fields [42,103–107,109–112]. It helps determine interdependencies, calculate weights, and address uncertainties, enhancing decision-making accuracy and effectiveness.

3. Proposed Methods and Framework

The methodology used in this study consists of three stages: identification of KPIs, determination of significant KPIs using the FDM, and examination of the cause-and-effect relationship among these KPIs and their ranks using the Fuzzy DEMATEL approach. The framework that integrates the two methodologies consists of three distinct stages, as seen in Figure 3.

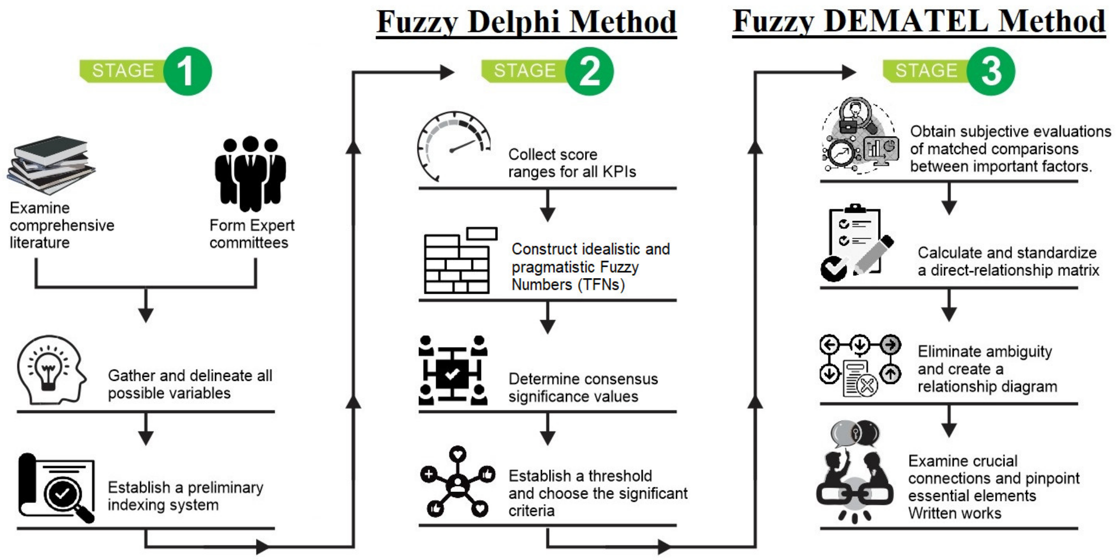

Figure 3. Proposed Framework.

3.1. Identification of KPIs

Although attempts have been made to encourage varied performance evaluations in humanitarian organizations, there are still certain indicators impeding progress towards the efficient performance of HOs. Humanitarian organizations still struggle to bridge the divide. Our goal is to gather these crucial indicators from a thorough perspective by conducting a literature review. It is essential to have a comprehensive classification of these indicators to gain a thorough grasp of performance measurement and identify the most crucial indicators. We tried to identify the significant KPIs using a detailed/comprehensive literature review and classify them based on quality, accountability, operational excellence, and sustainability for employing FDM.

3.2. Fuzzy Delphi Method

A widely used expert opinion communication strategy to distill consistent conclusions is FDM. Through multiple rounds of textual communication, experts can take advantage of obtaining feedback information and change earlier decisions. Its fundamental characteristics include statistical group replies, regulated and recurrent feedback, and anonymous responses. However, the conventional approach has significant drawbacks when it comes to providing ambiguous decision information, such as low convergence rates, skewed expert opinions, high execution costs, and so forth. The fuzzy Delphi approach was thus proposed as a solution to these flaws by incorporating fuzzy logic theory. TFNs are a means of expressing feedback to decision-makers. The fuzzy Delphi approach provides the subsequent benefits over the traditional approach: Final decisions can be reached by a single round of written communication rather than several rounds of communications and adjustments; it can reflect complete valuable information from ambiguous subjective judgments. Thus, the fuzzy Delphi method is introduced to recognize significant KPIs.

The fuzzy Delphi method is a method that combines subjective judgments with written communication to make final decisions. It is particularly useful in identifying significant KPIs. The process involves designing questionnaires to assess potential KPIs. Prior studies often relied on triangular [96,100,101], trapezoidal [102], and Gaussian [103] fuzzy numbers for choosing fuzzy membership functions. Witold has demonstrated that the widely employed triangle membership functions offer a direct resolution to the problems that arise in fuzzy modeling [104]. Kosheleva and Kreinovich, in their research, argued that triangular fuzzy numbers are best because TFNs are simple and intuitively clear methods [105,106]. So, we use in our research TFNs mentioned in Table 3 that indicate idealistic and pragmatistic. The maximum score interval indicates positive (idealistic) cognition, while the minimum indicates negative (pragmatistic) cognition. This method offers advantages over conventional methods. The main steps of the FDM are as follows and also illustrated in Figure 4, a graphical representation of FDM steps.

Table 3. TFNs corresponding to linguistic terms of FDM [99].

Linguistic Terms	TFNs
Very Low	(0, 0, 0.25)
Low	(0, 0.25, 0.5)
Medium	(0.25, 0.5, 0.75)
High	(0.5, 0.75, 1)
Very High	(0.75, 1, 1)

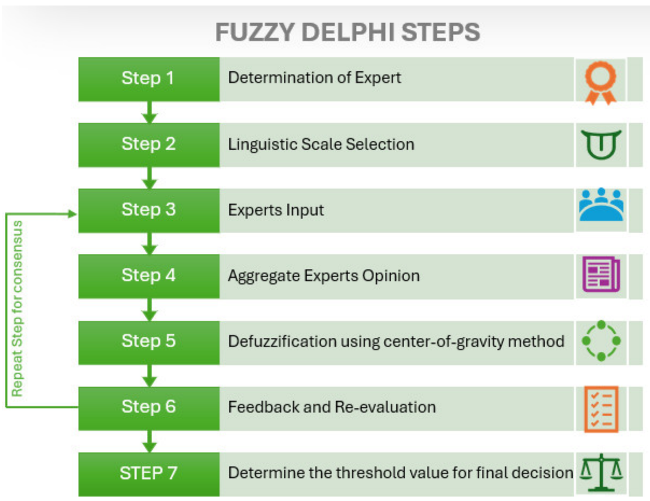

Figure 4. Fuzzy Delphi Method Steps.

Step 1: Determination of Experts

Proficient professionals in humanitarian relief logistics should be selected from government organizations, NGOs, media, academia, volunteers/disaster workers, and other relevant stakeholders to form a suitable expert group.

Step 2: Linguistic Scale Selection

Linguistic scales mentioned in Table 3 are used by the experts to express their opinions.

Step 3: Experts' Input

Let x, y, and z be the minimum, average, and maximum ways of representing opinions; they are considered TFN and can be written as:

$$\widetilde{E}_m = (x_m, y_m, z_m) \tag{1}$$

where $\widetilde{E}_m$ represents the fuzzy number for the criteria m. x_m, y_m and z_m can be represented as the minimum, average, and maximum number of experts' opinions.

Step 4: Aggregate Experts' Opinions

Calculate the aggregate TFN for each criterion. This can be done by averaging the minimum, average, and maximum values provided by all experts for each criterion:

$$\widetilde{X}_m = \sum_{i=1}^{n} x_{m,i} / n \tag{2}$$

$$\widetilde{Y}_m = \sum_{i=1}^{n} y_{m,i} / n \tag{3}$$

$$\widetilde{Z}_m = \sum_{i=1}^{n} z_{m,i} / n \tag{4}$$

where n is the number of experts.

Step 5: Defuzzification Using the Center-Of-Gravity Method:

The center-of-gravity method is used to defuzzify the obtained judgment opinions which can be computed with the assistance of the equation mentioned below:

$$L_m = \left(\widetilde{X}_m + \widetilde{Y}_m + \widetilde{Z}_m\right) / 3 \tag{5}$$

Step 6: Feedback and Re-Evaluation

Share the graphical representation of final results using the first round of FDM with experts. Each expert reviews the aggregated feedback and may adjust their initial opinions based on the collective input. Experts reassess their x_m, y_m, z_m values based on the aggregated results and the reasoning provided by other experts. Repeat Steps 3 to 5 until consensus is reached among selected experts.

Note: Conducting several rounds of FDM until consensus is reached among experts can ensure the consistency of the obtained results.

Step 7: Determine the Threshold Value for the Final Decision.

Once the consensus criterion is met, the final L_m values are used to decide on the acceptance of each criterion based on the threshold β.

The principles for the final selection of the criteria are as follows:

(1) If $L_m \geqslant \beta$, accept criterion m; and
(2) If $L_m < \beta$, omit criterion m.

β is a decision threshold used to determine the acceptance or omission of criteria based on their evaluated significance. The β value is determined by the decision-makers based on the achieved final results after reaching a consensus. If the calculated center-of-gravity L_m for a criterion meets or exceeds β, the criterion is accepted; if L_m falls below β, it is omitted. The threshold β thus serves as a critical benchmark for distinguishing between significant and less significant criteria in decision-making processes.

3.3. Fuzzy DEMATEL Method

The fuzzy DEMATEL technique is an effective instrument for addressing decision-making challenges and seeking comprehensive answers. It involves assigning a score of influence in the form of triangular fuzzy numbers (TFNs) to linguistic variables (qualitative data). The TFNs are mentioned in Table 4. Analysis of cause-and-effect relationships between evaluation criteria is made possible by the DEMATEL method. It can be utilized, using matrices or digraphs, to create a comprehensible structural model that includes the relationships among criteria and degrees of influential influence. Complex causal connections between criteria might be visualized to investigate based on a graph theory and to clarify certain issues [113]. Applying the fuzzy logic theory should broaden the traditional approach given the ambiguous judgments of experts. We present the fuzzy DEMATEL approach to address the fuzziness of decision-making in actual MCDM problems. Fuzzy linguistic variables can be used instead of exact numerical values to obtain subjective perspectives concerning various interactions and keep all the information needed to make decisions. Thus, the extended method is introduced to effectively analyze the causal structure of SHRL for HOs. The following are the computation procedures and Figure 5 illustrates the Fuzzy DEMATEL steps.

Table 4. Linguistic variables and their TFNs [103].

Linguistic Variable	Score	TFNs
Strongly agree	4	(0.7, 0.9, 1)
Agree	3	(0.5, 0.7, 0.9)
Normal	2	(0.3, 0.5, 0.7)
Disagree	1	(0.1, 0.3, 0.5)
Strongly disagree	0	(0, 0.1, 0.3)

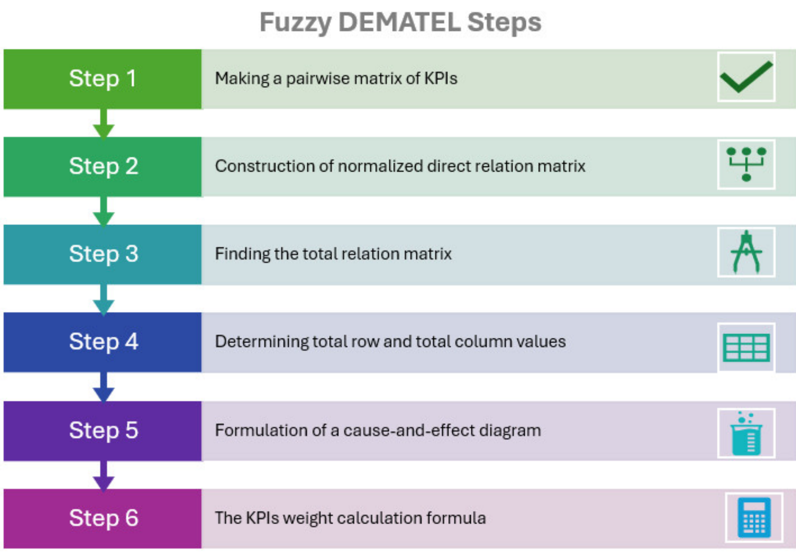

Figure 5. Fuzzy DEMATEL Steps.

Step 1: Making a Pairwise Matrix of KPIs.

Create a median direct relation matrix by assigning TFNs using a fuzzy linguistic scale. The relative importance of criteria i to j is shown by the element of the direct relation matrix $n \times n$ generated through pairwise comparison.

Converting fuzzy information to crisp scores (CFCS) facilitates the aggregation of fuzzy data. The crisp value is determined in CFCS's five main stages by averaging the weights of the fuzzy minimum and maximum values. Suppose $u_{ij}^{k} = \left(a_{ij}^{k}, b_{ij}^{k}, c_{ij}^{k}\right)$ indicates the three fuzzy judgments—lower, medium, and upper value—denoted by a, b, and c of evaluator k from criteria i to j: such that $k = 1, 2, 3 \ldots . p$. Here, p denotes the number of respondents. The five-stage algorithm for CFCS is given below.

1: Normalization

Equations (6)–(8) are used to normalize the obtained triangular fuzzy numbers.

$$xa_{ij}^{k} = (a_{ij}^{k} - \min a_{ij}^{k}) / \Delta_{\min}^{\max} \tag{6}$$

$$xb_{ij}^{k} = (b_{ij}^{k} - \min a_{ij}^{k}) / \Delta_{\min}^{\max} \tag{7}$$

$$xc_{ij}^{k} = (c_{ij}^{k} - \min a_{ij}^{k}) / \Delta_{\min}^{\max} \tag{8}$$

where

$$\Delta_{\min}^{\max} = \max c_{ij}^{k} - \min a_{ij}^{k} \tag{9}$$

Equation (9) and xa_{ij}^{k}, xb_{ij}^{k}, and xc_{ij}^{k} are the normalized values of a_{ij}^{k}, b_{ij}^{k} and c_{ij}^{k}, respectively.

2: Left and right normalized values

Equations (10) and (11) are utilized to calculate xls_{ij}^{k}, denoted as the left standard value, and xcs_{ij}^{k}, denoted as the right standard value.

$$xls_{ij}^{k} = xb_{ij}^{k} / (1 + xb_{ij}^{k} - xa_{ij}^{k}) \tag{10}$$

$$xcs_{ij}^{k} = xc_{ij}^{k} / (1 + xc_{ij}^{k} - xb_{ij}^{k}) \tag{11}$$

3: Total Normalized Crisp Value

The total normalized crisp value is calculated with Equation (12).

$$x_{ij}^{k} = \left[xls_{ij}^{k}(1 - xls_{ij}^{k}) + xc_{ij}^{k} \times xc_{ij}^{k}\right] / \left[1 - xls_{ij}^{k} + xcs_{ij}^{k}\right] \tag{12}$$

where x_{ij}^{k} is the total normalized value.

4: Crisp Value

After deblurring u_{ij}^{k} the crisp values with Equation (13).

$$u_{ij}^{k} = \min a_{ij}^{k} + x_{ij}^{k} \Delta_{\min}^{\max} \tag{13}$$

where u_{ij}^{k} denotes the crisp value of the influence of KPI i on KPI j assessed by expert p.

5: Combine Crisp Values

Compute u_{i}^{j} by Equation (14), where u_{ij}^{k} denotes the average value of the influence of KPI i on KPI j assessed by experts p.

$$u_{i}^{j} = \frac{1}{p}(u_{ij}^{1} + u_{ij}^{2} + u_{ij}^{3} + \ldots + u_{ij}^{l}) \tag{14}$$

Finally, the matrix U by u_{ij}^{k}, as its factor in row i and column j is the direct impact matrix; it will serve as the initial data for the DEMATEL technique.

Step 2: Normalized Direct Relationship Matrix Construction

The normalizing U matrix computes the normalized direct relation matrix, which serves as initial data for the DEMATEL method. Matrix U, the normalized version, indicated by M, is built with Equation (15). Matrix M is the direct relative severity matrix such that $M = \left[M_{ij}\right]_{n \times n}$ and $0 \le M_{ij} \le 1$.

The following formula is utilized to calculate the matrix:

$$M = \frac{U}{\max_{1 \le i \le n} \sum_{j=1}^{n} u_{ij}} \quad i, j = 1, 2, 3 \ldots n \tag{15}$$

where $\max_{1 \le i \le n} \sum_{j=1}^{n} u_{ij}$ denotes the KPI that has the most impact on other KPIs.

Step 3: Obtaining the total relationship matrix.

The KPIs of the direct and indirect relative severity matrix (DIRSM), represented with T with KPIs $t_{ij} > 0$ in row i, and column j are obtained by using Equation (16).

The total relationship matrix is determined by using a normalized matrix.

$$T = M(I - M)^{-1} \tag{16}$$

where I stands for the identity matrix. DIRSM contains all the direct and indirect relationships among the KPIs. Normally, $t_{ij} > 0$ means that KPI i is more influential than KPI j with a degree t_{ij}.

Step 4: Finding the sum of the total rows and columns.

Here, Q, which is the summation of each row, and S, which is the summation of each column, are the elements of C, which are obtained by Equations (18) and (19).

$$C = [t_{ij}]_{n \times n} \quad i, j = 1, 2, 3 \ldots n \tag{17}$$

$$Q = \left[\sum_{j=1}^{n} t_{ij} \right]_{n \times 1} \tag{18}$$

$$S = \left[\sum_{i=1}^{n} t_{ij} \right]_{1 \times n} \tag{19}$$

Here Q represents the influential degree of KPI i directly or indirectly exerted on all the other KPIs in the system, which is called the degree of influencing. S represents the influential KPI j directly or indirectly received from all the other KPI in the system, which is called the degree of influenced.

Step 5: Cause-and-Effect Diagram Formation

To form the prominence values, we add Q and S and form the relaxation value by subtracting Q and S. The values obtained after the addition of ($Q + S$) form the cause group, and the values obtained after the subtraction of ($Q - S$) form the effect side of the diagram.

When the value of i equal to j $(i = j)$, the addition of Q and S ($Q + S$) obtained values is called as degree of centrality, and values obtained after subtracting Q and S ($Q - S$) are called the degree of causality. The KPIs are then put in the order of by the values of $Q + S$ and $Q - S$, going from highest to lowest. KPI i is a dispatcher when $Q - S > 0$ and is a receiver when $Q + S < 0$. Generally, the summation value of $Q + S$ is more pertinent than that of subtraction values of $Q - S$. KPIs having larger values of $Q + S$ are assumed to have higher prioritization and have a stronger influence on others.

Step 6: The KPI weight calculation formula

The weight of the KPIs is calculated with the help of Equations (20) and (21) to rank the KPIs. When the value of W_i is high, the rank of that KPI is most important in the performance measurement system.

$$W_i = \left[(Q_i + S_i)^2 + (Q_i - S_i)^2 \right]^{1/2} \tag{20}$$

$$w_i = W_i / \sum_{i=1}^{n} W_i \quad (21)$$

4. Results

This section discusses the results obtained from scientific calculations on data collected from expert's opinions and the literature review.

4.1. Establish a Preliminary Indexing System and Selection of KPIs Using Fuzzy Delphi

The Delphi approach, which was popularized by the Rand Corporation, combines expert viewpoints to establish selection criteria. Nevertheless, it lacks extensive coverage of expert viewpoints and incurs higher execution costs. Murray et al. [114] and Ishikawa et al. [97] used the Fuzzy Delphi technique, a quantitative approach that addresses uncertainty and vagueness. This approach is currently being utilized in many new fields, such as vendor selection, medical and engineering fields. A questionnaire was created using linguistic scales mentioned in Table 3 and distributed to experts. Proficient expert panels guarantee the precision of data and study findings. 19 qualified participants, comprising government officials, non-government managers, professors, journalists, reputed and educated social workers, and volunteers, attended communication meetings and group discussions. Their judgment should be integrated into decision-making procedures. Distinctive features and field experience of the expert group are mentioned in Table 5.

Table 5. Summary of the expert group with practical field experience.

Expert Group Name	Education Level	Experience (Years)	Participants	Professional Field
EG—1	Post Graduation/Ph.Ds.	≥10	3	Government Departments
EG—2	Post Graduation	≥5	7	Non-Government Organization
EG—3	Ph.Ds.	≥15	4	Academicians/Professors
EG—4	Graduation/Post Graduation	≥5	2	Media
EG—5	Graduation or above	≥5	3	Volunteers/Disaster Workers

The team coordinator organized meetings with expert groups to discuss and select the KPIs. We analyzed the literature and reports to identify probable KPIs that are important to measure the performance of HOs. The criteria were divided into four dimensions—Quality, Accountability, Operational Excellence, and Sustainability—according to the relevance of KPIs. The preliminary findings that were generated as a result of these meetings form an initial index system described in Table 6. The experts divided the parameters into four groups and named them accordingly, as described in the paragraphs below. Logically these parameters and groups are closely related to "Quality", "Accountability", "Operational Excellence", and "Sustainability".

4.1.1. Quality (P1)

Quality is a multifaceted concept encompassing performance, durability, reliability, functionality, aesthetics, emotional impact, cultural significance, and personal preference. It encompasses overall excellence and can vary depending on context, object, or individual. Quality is perceived differently by individuals in different circumstances; industrialists prioritize efficiency and improvement while buyers assess quality from a product perspective, and so on. While there are several definitions of quality, in essence, it may be said that quality is satisfying or exceeding consumer expectations. The pursuit of quality is a continuous, iterative process that involves setting clear goals, implementing effective standards, and continuously striving for improvement. In humanitarian logistics, where every action can impact lives in desperate need, the pursuit of quality takes on a specific and critical meaning. It is not just about efficiency or cost-effectiveness, but about delivering the right aid, to the right people, at the right time, and in the right condition. Therefore, the KPIs relevant to speedily delivering aid are put into this group by consensus of expert opinions through FDM.

Delay in the delivery of relief items to the affected population will affect the overall performance of the HOs, which leads to dissatisfaction among donors as well as other stakeholders. Moreover, prompt delivery is a critical aspect of measuring service quality in the delivery of relief items, as it immediately affects the dependability and efficacy of relief activities. Furthermore, delivery accuracy guarantees that the relief items reach the right people, and trustworthiness in delivery ensures the prevention of inconsistency and the fostering of mutual trust among stakeholders and receivers.

Table 6. Significant Drivers for Performance Measurement of HOs.

Group	Sub-Group	Description
➢ Quality	○ Prompt Delivery	Prompt delivery refers to the timely and efficient transportation of goods or services to their intended recipients within the agreed timeframe, with punctuality being a crucial factor, while promptness refers to the speed of delivery.
	○ Delivery Accuracy	Delivery accuracy refers to the quality or precision of goods and services, ensuring they accurately match specifications and requirements.
	○ Trustworthiness of delivery	Trustworthiness of delivery measures consistency and dependability in terms of quantity, quality, and availability.
	○ Responsive Delivery	Responsiveness measures flexibility and adaptability to changing needs.
	○ Satisfied Delivery	Satisfaction measures how satisfied beneficiaries, donors, and humanitarian organizations are with the goods and services provided.
	○ Delivery Grievances	An expression of dissatisfaction. A delivery grievance is a complaint that can be formal.
	○ Delivery Errors	A failed delivery in logistics can occur when there is an error in the shipping address, a human error by the driver, or the driver does not meet the required time window.
➢ Accountability	Delivery transparency	Delievry transparency which assesses how accessible the information and communication about the goods and services are to stakeholders and the public.
	Delivery Participation	Delivery participation should be monitored to measure how inclusive and representative the involvement of affected populations and other stakeholders is in the planning, implementation, and evaluation of goods and services.
	Delivery Feedback	Feedback should be assessed to determine how effective and responsive the mechanisms for receiving and addressing complaints, suggestions, and compliments from beneficiaries are.
	Capacity Building and Training	CBT should be evaluated to ascertain how systematic and continuous the processes for collecting, analyzing, and applying lessons learned and best practices from goods and services are.
	Delivery Compliance	Compliance should be surveyed to gauge how well goods and services adhere to relevant laws, regulations, policies, standards, and codes of conduct.
	Stakeholder Engagement	Stakeholder engagement involves identifying, analyzing, planning, and implementing actions to influence stakeholders, ensuring inclusive and representative participation in the planning, implementation, and evaluation of goods and services.

Table 6. *Cont.*

Group	Sub-Group	Description
➢ Operational Excellence	○ Resource Utilization	To evaluate resource utilization, one measures how optimal the use of resources is for goods and services.
	○ Impact Assessment	Impact assessment measures how well goods and services achieve intended objectives.
	○ Adaptive Capacity	Adaptive capacity measures how robust and adaptable goods and services are to cope with shocks.
➢ Sustainability	○ Pollution Control	Pollution measures how to use a carbon footprint. A carbon footprint is a measure of the amount of carbon dioxide and other greenhouse gases emitted by an activity, service, or product.
	○ Resource Conservation	Resource conservation measures how goods and services reduce waste and degradation of natural resources.
	○ Local Communities Empowerment	Community empowerment refers to the process of enabling communities to increase control over their lives.
	○ Labor Condition	How humanitarian organizations take care of the secure working conditions and health of their workers in humanitarian relief activities.
	○ Political instability	Political instability refers to the probability of a government failing as a result of disagreements or competition among political parties.
	○ Logistics Disputes and Trade Disputes	A logistics dispute involves supply chain disagreements, while a trade dispute involves disagreements between workers and employers, or between countries over traded products.
	○ Legislation and Regulatory Amendments	Logistics legislation and regulatory amendments involve various regulations covering customs, transportation, safety, environmental concerns, and trade agreements, regulated by legislation or Acts of Parliament, and amendments.
	○ Minimize Total Cost	Economic impact measures positive effects on income, livelihoods, markets, and infrastructure, while cost minimization reduces unnecessary or inefficient expenditures.
	○ Financial Efficiency	Financial efficiency refers to an organization’s ability to efficiently convert expenses into revenue and achieve goals with minimal waste, effort, or energy.

4.1.2. Accountability (P2)

Accountability is a crucial aspect of ethical behavior, successful relationships, and effective systems. It involves taking responsibility for one’s actions and decisions and being accountable for the consequences. It benefits individuals, organizations, and society at various levels. It fosters self-awareness, builds trust, and leads to professional success. Clear accountability structures ensure performance, ethics, and transparency. It promotes fairness and order in decision-making processes. Collective accountability is essential for addressing global challenges like climate change and poverty. Key aspects of accountability include clarity, transparency, fairness, and support. Implementing accountability can be challenging due to resistance to change and power dynamics. However, it can lead to increased trust, collaboration, decision-making, and innovation.

In the context of SHRL, accountability in humanitarian operations depends critically on transparency since it enables stakeholders to examine the distribution of funds and decision-making procedures. Taking part in the organization and carrying out of humanitarian operations guarantees that aid satisfies the needs of vulnerable people, thereby democratizing the procedure. Evaluation of the efficiency of aid and improvement of accountability depends on beneficiary and other stakeholders' input. Continuously gaining knowledge from operational experiences raises effectiveness and efficiency and shows that an organization is dedicated to learning and changing its operations. Following international laws and regulations guarantees moral and legal behavior, which strengthens responsibility and protects the rights of stakeholders. Therefore, by consensus of experts using FDM and measuring the performance of HOs, it is necessary that all the actions are transparent, that concerns of all stakeholders involved in the whole process are known, and that the delivered items reach the right persons. The KPIs delivery transparency, stakeholder engagement, delivery feedback, capacity building and training, delivery compliance, and delivery participation are included in accountability.

Accountability in humanitarian operations is crucial for enhancing governance, integrity, and effectiveness. It involves creating a transparent, participative, and responsive environment where organizations are accountable to stakeholders. This approach ensures responsible actions and continuous improvement based on stakeholder input. Integrating accountability factors into humanitarian logistics operations ensures aid delivery is effective, ethical, and responsible management. This fosters public trust and support, essential for long-term sustainability and impact of humanitarian organizations.

4.1.3. Operational Excellence: (P3)

The synchronization between operational activities (internal) and logistics activities (external) is indispensable to ensure enduring HOs' performance. Operational Excellence refers to the process of developing and utilizing resources inside an organization to achieve competitive advantages in a dynamic and uncertain environment. Drivers/enablers/critical success factors and problems/barriers/challenges of the operational excellence approach exist for sustainable supply chains and their performance improvement. Operational excellence approaches and knowledge management models play roles in sustainable supply chain flexibility, collaboration, dynamism, transparency, relational capabilities, and innovation performance. Contradictory and unexpected outcomes and relationships, such as operational excellence, may upset some aspects of ecological or social sustainability. Operational excellence is the ability to improve, change, and optimize commercial processes using technological, cultural, and organizational factors. It is a strategic part of business growth, supporting growth and meeting stakeholder expectations. In today's competitive market, organizations must not only react reactively but also seek long-term success by achieving excellence in their business. Operational excellence involves lean processes, and delivering value to customers at low prices and with convenience. In humanitarian logistics, resource use is critical to maximizing output and reducing needless work. Costs are lowered, response times are sped up, and performance is generally improved. Impact evaluation guarantees that aid satisfies the requirements of the population, synchronizes efforts with the objectives of the mission, and improves quality. Resilience is increased by adaptive capability, which enables businesses to plan for, react to, and bounce back from setbacks, thereby ensuring sustainability and disaster resilience.

4.1.4. Sustainability (P4)

Sustainability is the goal of meeting current needs without compromising future generations' ability to meet theirs. It involves addressing environmental, economic, and social factors. The environmental pillar focuses on renewable energy, responsible resource management, and conservation efforts. The economic pillar focuses on resource-efficient economic models, creating decent jobs, and promoting fair trade practices. The social pillar focuses on creating a just and equitable world for all, addressing issues like poverty and inequality. Achieving sustainability requires a multi-pronged approach from individuals, businesses, and governments. By making conscious choices, businesses can integrate sustainability into their operations, and governments can incentivize sustainable practices and invest in green technologies.

SHRL is influenced by several indicators mentioned in Table 6, which were categorized into four groups by experts and proved by the study that these four groups are essential to measure the performance of HOs. Figure 6 demonstrates these four groups as the pillars of SHRL.

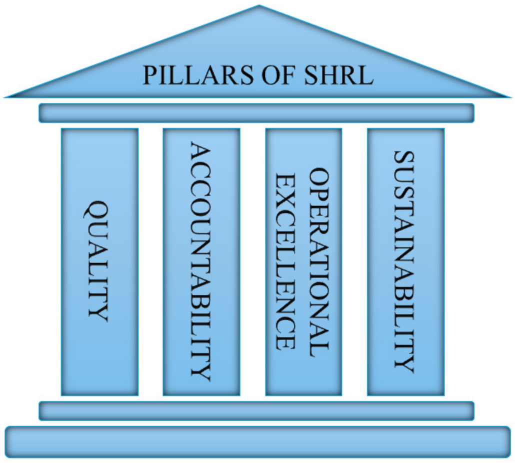

Figure 6. Description of Pillars of SHRL.

4.2. Recognizing the Significant KPIs

The FDM, which involves a systematic and iterative approach to gathering expert opinions, was utilized to identify the most significant KPIs from the preliminary index system. This study utilized fuzzy set theory with the Delphi method to enhance the consistency of expert opinions by effectively tackling data uncertainty. The five expert groups responded to a survey at the communication meeting. The experts provided their opinions on the relative importance of KPIs using the score intervals in Table 3. The expert opinions were collected and represented from idealistic and pragmatic perspectives by using Equation (1). By doing so, a wide range of expert viewpoints were included on the significance of each criterion. The expert opinions were aggregated by calculating the average of their minimum, average, and maximum values. This resulted in aggregated TFNs for each criterion using Equations (2)–(4). These aggregated TFNs can then be used for further analysis. Later on, the CoG method mentioned in the equation was employed to defuzzify the aggregated opinions by using Equation (5). The Fuzzy Delphi approach is employed to filter the critical KPIs. The threshold setting for filtering has an impact on the quantity of parameters. A larger value would result in a more stringent filtering of criteria, significantly affecting this research. In this study, a threshold value of 0.6 has been established, as it represents the average between the minimum value considered (0.5) and the maximum value considered (0.7). The conclusive outcomes are displayed in Table 7.

Table 7. Fuzzy Delphi Results of KPIs.

Main Criteria	Sub Criteria	Value Results	Accepted/Rejected
Quality (P1)	Prompt Delivery	$0.84 \geq 0.6$	Accepted
	Delivery Accuracy	$0.63 \geq 0.6$	Accepted
	Trustworthiness of delivery	$0.94 \geq 0.6$	Accepted
	Responsive Delivery	$0.81 \geq 0.6$	Accepted
	Satisfied Delivery	$0.75 \geq 0.6$	Accepted
	Delivery Grievances	$0.58 < 0.6$	Rejected
	Delivery Errors	$0.56 < 0.6$	Rejected

Table 7. *Cont.*

Main Criteria	Sub Criteria	Value Results	Accepted/Rejected
Accountability (P2)	Delivery transparency	$0.70 \geq 0.6$	Accepted
	Stakeholder Engagement	$0.64 \geq 0.6$	Accepted
	Delivery Feedback	$0.83 \geq 0.6$	Accepted
	Capacity Building and Training	$0.66 \geq 0.6$	Accepted
	Delivery Compliance	$0.62 \geq 0.6$	Accepted
	Delivery Participation	$0.44 < 0.6$	Rejected
Operational Excellence (P3)	Resource Utilization	$0.86 \geq 0.6$	Accepted
	Impact Assessment	$0.77 \geq 0.6$	Accepted
	Adaptive Capacity	$0.61 \geq 0.6$	Accepted
Sustainability (P4)	Pollution Control	$0.66 \geq 0.6$	Accepted
	Resource Conservation	$0.64 \geq 0.6$	Accepted
	Local communities Empowerment	$0.78 \geq 0.6$	Accepted
	Labor Condition	$0.71 \geq 0.6$	Accepted
	Political instability	$0.42 < 0.6$	Rejected
	Logistics Disputes and Trade Disputes	$0.57 < 0.6$	Rejected
	Legislation and Regulatory Amendments	$0.52 < 0.6$	Rejected
	Minimize total Cost	$0.73 \geq 0.6$	Accepted
	Financial Efficiency	$0.86 \geq 0.6$	Accepted

Figure 7 illustrates the findings of the Fuzzy Delphi analysis, where 19 KPIs are chosen for further examination using the Fuzzy DEMATEL technique and categorized into four primary groups based on criteria with variable names. The figure illustrates the relative importance and ranking of each criterion used in the Fuzzy DEMATEL approach.

Figure 7. Fuzzy Delphi accepted KPIs with variable names.

4.3. Fuzzy DEMATEL

After FDM and selecting critical KPIs by the expert opinions, the fuzzy DEMATEL method is applied to obtain the cause-and-effect relationship among KPIs and establish a structural model. Participants evaluated each KPI using a five-point linguistic scale. Table A1 in Appendix A displays the outcome of an expert's assessment, illustrating the impact of one KPI on the others. According to the given table, the expert argues that D1 has a very strong impact (SA) on D2, D3, D4, D6, D10, D16, D17, and D18, and a medium impact on D5, D8, D9, D11, D12, and D19. He also elaborates that D1 has no impact on D13. Furthermore, D1 has a high impact on the remaining indicators D7, D14, and D15.

The respondents' reactions, represented as influence scores are transformed into TFNs. As an illustration, the linguistic variable "Strongly Agree" (SA) with an influence score of 4 is converted into fuzzy numbers (0.7, 0.9, 1), which is represented in Tables A2 and A3 in Appendix A. The process involves utilizing an Excel sheet and implementing the CFCS defuzzification procedure, as described in Equations (6)–(14), to transform fuzzy integers into precise values. Later on, Equation (15) was utilized to obtain the direct relationship matrix, represented in Table A4 of Appendix A. Subsequently, Equation (16) was used to calculate the total relationship matrix. The results of the cause-and-effect diagram are calculated by using Equations (17)–(19) and shown in Figure 8. By adding Q and S (Q + S) to obtain the horizontal values (x-axis) of the diagram, meanwhile subtracting Q and S (Q − S) to obtain the vertical values (y-axis) of the cause-and-effect diagram to describe the KPIs' importance and interconnection with each other. Table 8 illustrates the results of KPI weights obtained by using Equations (20) and (21).

Table 8 shows the ranking of the KPIs and concludes that prompt delivery (D1) is the main factor in the cause group with the highest vertical axis value (0.0553). Prompt delivery is crucial in disaster management and humanitarian logistics, as it directly impacts various factors. It ensures the effectiveness of relief efforts, builds trust and confidence among stakeholders, and enables timely responses to evolving needs. It also contributes to beneficiary satisfaction by meeting their immediate needs, reducing frustration and disappointment. Prompt delivery also enhances operational efficiency by minimizing bottlenecks and optimizing logistics processes. It also promotes transparency and accountability in relief operations, providing stakeholders with clear visibility into their actions and decision-making processes. Therefore, prioritizing timeliness ensures aid reaches those in need promptly, maximizes the impact of relief interventions, and fosters trust and confidence among stakeholders involved in relief operations.

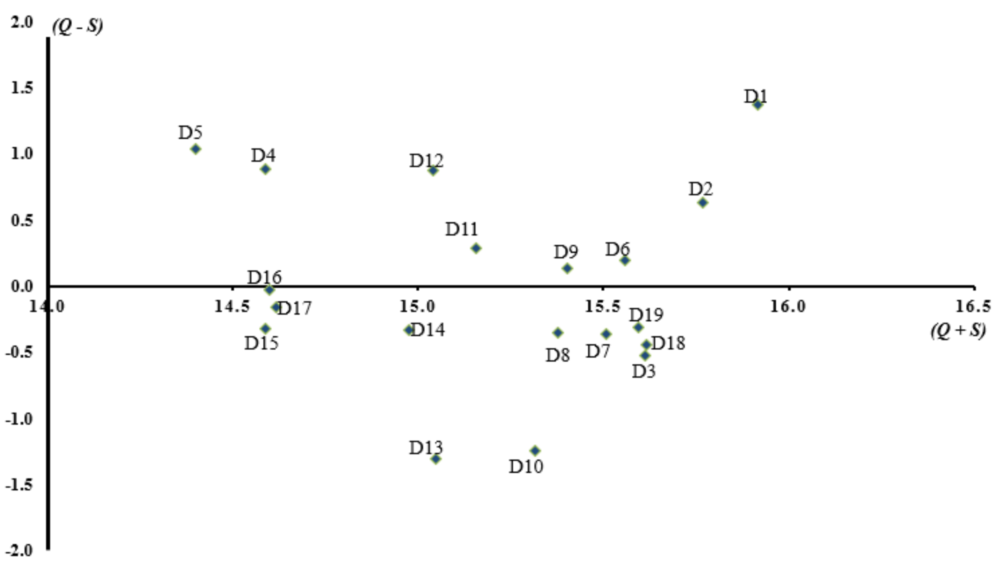

Figure 8. Cause-and-effect diagram of KPIs.

Table 8. Final weightage and Ranking of KPIs.

Criteria	KPIs	Q	S	Q + S	Q − S	Group	KPIs Weights	Dimensional Weights	KPIs Rank
P1	D1	8.6448	7.2716	15.9164	1.3731	Cause	0.0553	13.8581	1
	D2	8.1965	7.5703	15.7668	0.6261	Cause	0.0546		2
	D3	7.5424	8.0685	15.6109	−0.5261	Effect	0.0541		4
	D4	7.7358	6.8506	14.5864	0.8852	Cause	0.0506		16
	D5	7.7150	6.6829	14.3979	1.0321	Cause	0.0500		19
P2	D6	7.8740	7.6831	15.5572	0.1909	Cause	0.0538	13.5877	6
	D7	7.5737	7.9353	15.5089	−0.3616	Effect	0.0537		7
	D8	7.5101	7.8676	15.3778	−0.3575	Effect	0.0532		9
	D9	7.7661	7.6369	15.4029	0.1292	Cause	0.0533		8
	D10	7.0354	8.2786	15.3140	−1.2432	Effect	0.0532		10
P3	D11	7.7218	7.4333	15.1550	0.2885	Cause	0.0525	13.3844	11
	D12	7.9556	7.0835	15.0391	0.8721	Cause	0.0521		13
	D13	6.8688	8.1806	15.0493	−1.3118	Effect	0.0523		12
P4	D14	7.3217	7.6536	14.9753	−0.3319	Effect	0.0518	13.1815	14
	D15	7.1318	7.4542	14.5860	−0.3224	Effect	0.0505		18
	D16	7.2845	7.3141	14.5986	−0.0297	Effect	0.0505		17
	D17	7.2280	7.3897	14.6177	−0.1617	Effect	0.0506		15
	D18	7.5875	8.0297	15.6172	−0.4422	Effect	0.0541		3
	D19	7.6420	7.9513	15.5934	−0.3093	Effect	0.0540		5

The cause-and-effect diagram shows that all nineteen KPIs are interconnected with each other, have strong and weak impacts on one another, and are compulsory for SHRL performance measurement frameworks. In Table 8, the ranks of KPIs mention that prompt delivery (D1), and delivery accuracy (D2) have the highest ranking in the cause group which means that if D1 and D2 are achieved by any HO, then this organization performed better in every aspect to meet the quality standards of international donor organizations.

5. Discussion

Performance measurement in the field of humanitarian relief logistics and supply chain management is of utmost importance due to the expanding magnitude and complexity of natural disasters, diminishing financial assistance from governments, and intensifying competition for limited donations. Researchers propose implementing comprehensive and well-rounded strategies derived from the business sector. However, the existing performance measurement frameworks in HRL suffer from a lack of emphasis on prioritizing performance KPIs and considering sustainable practices. This leads to a problem and paves the way for developing a comprehensive framework that integrates sustainability considerations into performance measurement metrics in HRL and how to measure the performance of HOs' logistics and supply chains.

The study contributes to addressing this gap in SHRL performance measurement. It proposes a scheme for SHRL performance measurement using an integrated Fuzzy Delphi-DEMATEL approach. The results obtained from Fuzzy Delphi-DEMATEL are discussed in this section. Figure 8 illustrates the cause-and-effect diagram and is described as follows: The KPIs prompt delivery (D1), delivery accuracy (D2), responsive delivery (D4), satisfied delivery (D5), delivery transparency (D6), capacity building and training (D9), resource utilization (D11), and impact assessment (D12) are divided into the cause group, while trustworthiness of delivery, stakeholder engagement, delivery feedback, delivery compliance, pollution control, resource conservation, local community empowerment, labor conditions, minimizing total cost, and financial efficiency fall into the effect criteria group. The cause group helps disaster management and humanitarian aid decision-makers by analyzing system dynamics and relationships. It identifies causal links between variables, helping HOs to prioritize actions, allocate resources, and implement focused solutions. The importance of prompt delivery (D1) is very high and ranks in the first position as its weight is 0.0553, which shows its impact on the whole system of PMMSHRL. The value for Q of D1 in Table 8 is 8.6448, which is also top-ranked among all values of the influential group. Hence, D1 has a significant impact and influence on other criteria. The criteria "Quality" and its sub-KPIs D1, D2, D3, D4, and D5 are crucial for the performance measurement of humanitarian organizations to achieve their major goal of serving people in disaster areas. Hence, it is proved that these KPIs are vital for the reliability, responsiveness, and satisfaction of relief efforts. They build trust, enable quick responses to needs, and enhance operational excellence, allowing for effective resource allocation and targeted strategies. In this study, prompt delivery (D1) and delivery accuracy (D2) are the KPIs that impact and improve responsive delivery (D4) and satisfied delivery (D5), fostering trustworthiness of delivery (D3), thus optimizing humanitarian logistics strategies and improving outcomes regarding accountability and sustainability effectively and efficiently. These KPIs are called quality measures, and most humanitarian organizations like the Sphere develop quality standards to measure the performance of Hos, and this empirical analysis is conducted with the help of multi-criteria decision-making models using fuzzy Delphi-DEMATEL. The dimensional weights are calculated using the same process for weights of KPIs. Quality has gained significant attention in the whole system with a weight of 13.8581.

The effect group contained trustworthiness of delivery, stakeholder engagement, delivery feedback, delivery compliance, pollution control, resource conservation, local communities' empowerment, labor conditions, minimizing total cost, and financial efficiency.

In summary, the results and discussion highlight the complex interplay between various causal factors and their effects on the effectiveness, efficiency, and sustainability of humanitarian relief activities. By understanding these relationships, organizations can better prioritize their efforts, allocate resources effectively, and enhance their capacity to respond to disasters and support affected communities.

The Fuzzy DEMATEL method is a crucial tool for building cause-and-effect diagrams and interrelationships among KPIs for measuring HOs' performance in humanitarian relief activities. It identifies key aspects of relief operations that directly impact operational excellence. These include prompt delivery, delivery accuracy, trustworthiness, and responsive and satisfied delivery. Delivery transparency, participation, and feedback mechanisms are essential for promoting accountability, and continuous learning. Learning from past experiences, compliance with standards, and efficiency contribute to sustainable relief logistics. Figure 9 demonstrates the average weights of KPIs. The diagram illustrates how these factors interact and influence each other, enhancing responsiveness and effectiveness in delivering aid. The KPIs resource utilization (D11), impact assessment (D12), and adaptive capacity (D13) are categorized under operational excellence. D11 and D12 are placed in the cause group by the calculations, which shows that they impact adaptive capacity. When we take it with the whole system and combine it with quality measures KPIs, we conclude that prompt delivery is directly connected with operational excellence. Resource utilization (D11) is the process of assessing the allocation, deployment, and efficiency of resources, and impact assessment (D12) evaluates the consequences of a disaster on human lives, infrastructure, economy, environment, and social structures. Adaptive capacity measures how robust and adaptable goods and services are to cope with disasters. Inadequate resource utilization (D11) and impact assessment can lead to increased severity of disaster impacts and disturb the adaptive capacity of the system, which ultimately destroys the whole process of SHRL, delaying aid delivery and limiting mitigation measures.

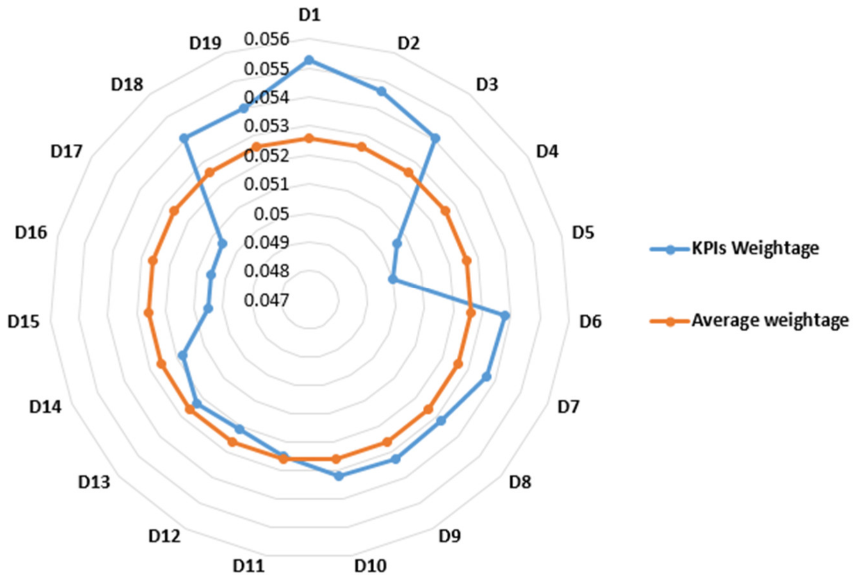

Figure 9. KPIs average weight.

The Fuzzy Delphi-DEMATEL methods for the KPIs identified in this study help to improve the theoretical implications in the field of SHRL and disaster management. They also explore the use of these methods in the performance measurement model for the sustainable development of humanitarian relief logistics and disaster management. The identified KPIs potentially contribute to theoretical advancement. The study demonstrates the practicality and effectiveness of fuzzy analysis in sustainable humanitarian relief logistics, contributing to the development of theoretical and empirical approaches in SHRL.

5.1. Theoretical Implications

The findings suggest the theoretical implication of the proposed SHRL framework, which incorporates all four dimensions of performance measurement: quality, accountability, operational excellence, and sustainability. It provides a comprehensive evaluation of KPIs and delivers valuable insights into the intricate priorities of performance measurement in SHRL. Previous studies have failed to consider the drivers of uncertainty and vagueness, as well as the exclusion of KPIs associated with sustainable practices [115]. In this context, a new approach has been proposed for tackling the multiple-faceted perspectives of performance measurement through Fuzzy Delphi-DEMATEL for SHRL. According to old data, individual performance was focused on without concentrating on several aspects, including but not limited to transparency, accountability, quality, efficiency, and sustainability of humanitarian relief logistics. In the current research, an integrated Fuzzy Delphi-DEMATEL approach has been adopted to measure the performance of HOs and address the existing shortcomings. This will not only improve the performance measurement concepts in SHRL but also consolidate KPIs into a comprehensive performance notch through implementing and prioritizing KPIs. Additionally, to improve the uncertainty examination based on the consolidation of KPIs by using the Fuzzy Delphi-DEMATEL approach, which deals with the ambiguities that are inherent in humanitarian logistics, leads to determining the unexpected working conditions. Therefore, the current study will tend to improve sustainable humanitarian relief logistics by advancing theoretical and empirical performance measurements of Fuzzy Delphi-DEMATEL analysis. It also provides efficiency improvement for measuring diverse humanitarian settings by combining fuzzy logic with established techniques like the Delphi and DEMATEL methods.

5.2. Managerial Implications

This study aims to enhance the application of SHRL by utilizing 19 critical KPIs. The findings provide many managerial implications. It would be crucial to prioritize the cause group criteria because they have a significant impact on the effect group criteria [105]. In simple terms, the criteria for the cause group are challenging to implement, whereas the requirements for the effect group are easily executed. The results indicate that managers should pay attention to four dimensions of SHRL: quality (P1), accountability (P2), operational excellence (P3), and sustainability (P4). In these four dimensions, KPIs D1, D2, D4, D5, D6, D9, D11, and D12 are in the cause group. The table shows that D1 and D2 have the highest weights and are placed at the top of the cause group, which means they have a significant overall impact. It demonstrates that if the relief goods reach vulnerable people in the stipulated time accurately, then the performance of the whole system is extraordinary. The effect group KPIs are D3, D7, D8, D10, D13, D14, D15, D16, D17, D18, and D19, in which D18 and D19 are ranked at the top of the effect group. The overall impact of D18 and D19 on the whole system is significant, as prompt and accurate delivery guarantees financial effectiveness and efficiency.

The most important criterion that influences SHRL is prompt delivery (D1). From a managerial perspective, prompt and accurate delivery enhances overall operational efficiency and has a direct impact on the ability to meet the immediate needs of the disaster-affected population, enabling resources to reach beneficiaries quickly and efficiently [6,73,78]. This is proven through findings that KPIs prompt delivery (D1) and delivery accuracy (D2) have an overall strong impact on the complete performance measurement system. Furthermore, minimization of total cost (D18) is proven to be of almost equal importance with the financial efficiency (D19) criterion. It is crucial to incorporate environmental factors such as pollution control (D14) and resource conservation (D15) into management decision-making to mitigate adverse environmental effects and foster sustainable practices in disaster relief operations [52,53].

6. Conclusions

This study provides a comprehensive analysis of drivers that improve humanitarian aid performance for humanitarian organizations. These drivers are significant for measuring the performance of HOs. Key performance indicators were identified to help stakeholders like governments, NGOs, donor agencies, and beneficiaries effectively overcome serious issues. Our study presents a simplified and effective approach to efficiently address and coordinate the distribution of relief to individuals. However, our study also contributes to minimizing negative impacts on the environment while simultaneously promoting sustainable development in terms of all dimensions of sustainability, such as environmental improvement, economic stability, and social satisfaction. The following are the primary research outcomes that have been presented.

A research framework that integrates fuzzy logic with Delphi and DEMATEL techniques was developed using the initial index system. A total of nineteen KPIs were selected by the fuzzy Delphi technique and divided into four groups through FDM: “Quality”, “Accountability”, “Operational Excellence”, and “Sustainability”. Using the fuzzy DEMATEL method, we were able to determine the cause-and-effect relationships among KPIs. Moreover, the expert groups’ evaluations were also conveyed through linguistic ratings, enabling easy and effective calculation of key performance indicators.

Systems thinking emphasizes the interconnected nature of relief operations. These insights can inform the design and implementation of more effective and sustainable relief strategies, promoting social justice and building resilient societies. The study emphasizes the significance of prompt delivery in disaster management and sustainable humanitarian relief logistics, highlighting its effectiveness, reliability, responsiveness, beneficiary satisfaction, operational efficiency, transparency, and accountability. Prompt delivery is crucial for the success of humanitarian relief operations, influencing response times, beneficiary satisfaction, operational effectiveness and efficiency, and overall disaster management.

However, despite its significance, challenges, and barriers to prompt delivery persist. These may include logistical constraints, transportation issues, bureaucratic delays, funding limitations, and infrastructure gaps.

Limitations and Future Directions

In this paper, the FDEMATEL approach is quite important for assessing the interdependent relationships among KPIs. Nevertheless, instead of computing dimensional influences (P1 to P4) directly using DEMATEL, the focus of this work is on identifying and prioritizing KPIs. The study aims to give practitioners and scholars a thorough understanding and use of KPIs pertinent to SHRL. Through the attention to significant KPIs, the study offers useful information on the performance measurement system that affects SHRL. Decision-makers can benefit greatly from the study's classification and analysis of KPIs even though the precise computation of dimensional influence is not addressed. The FDEMATEL approach has promise for evaluating cause-and-effect interrelationships and prioritizing significant KPIs in the larger framework of SHR; thus, researchers should investigate it further in future research. In conclusion, the study recognizes that the FDEMATEL approach is still a potent instrument for system-level analysis; hence, it purposefully limits its focus to certain KPIs. By doing so, it advances the field by emphasizing feasible KPIs that improve sustainability, efficiency, and accountability in SHRL.

Advancements in disaster management and humanitarian aid delivery will aid in enhancing the promptness of future research. Therefore, they will pave the path towards innovations in artificial intelligence, drones, and blockchain technologies. Many stakeholders from diverse sectors may play critical roles and can take advantage of capacity building, running programs, and empowering disaster-affected communities for the decision-making process. Meanwhile, regulatory measures and policy reforms can be executed for the efficient delivery of aid. Additionally, stakeholders can also take part in improving the outcomes of disaster management through the responsiveness and effectiveness of relief operations, ultimately improving outcomes for disaster-affected populations. Disaster management and humanitarian relief operations can be improved through artificial intelligence, blockchain management, and IoT. It may result in improving supply chain visibility, streamlining logistics, and expediting the delivery response. Therefore, these programs may result in strengthening the skills of relief workers and professionals. In addition to this, community-centric approaches enable disaster-affected communities to contribute to decision-making processes and relief efforts.

7. Patents

No patent is registered for this research work.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Expert Opinion Matrix.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19
D1	1	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA	SA
D2	I	1	A	I	A	I	SD	I	A	D	I	D	SA	SA	SA	I	A	SA	A
D3	A	D	1	D	A	I	A	I	A	I	I	SD	SA	SA	SA	A	A	SA	A
D4	I	SD	D	1	A	D	D	SD	A	A	A	SD	A	A	SA	D	I	A	I
D5	I	D	D	SD	1	A	I	D	SA	A	SA	SD	A	A	A	D	SD	SD	SD
D6	SA	A	SA	A	A	1	D	I	D	SD	I	SD	SA	SA	SA	I	I	A	D
D7	A	D	I	I	D	A	1	D	D	I	A	SD	SA	SA	SA	D	SD	A	D
D8	I	I	I	D	D	D	A	1	A	A	I	D	I	SA	SA	I	I	A	D
D9	I	D	A	A	A	SD	D	A	1	SD	I	D	SA	SA	SA	D	A	SA	A
D10	SA	SD	SD	D	D	SD	SD	A	I	1	I	D	SD	SD	A	D	A	D	SA
D11	I	A	SA	SA	A	A	A	SA	A	A	1	D	A	D	A	A	A	I	D
D12	I	SA	SA	SA	A	SA	A	SA	I	I	SD	1	I	D	A	SA	I	D	I
D13	A	SA	SA	SA	SA	A	I	SA	I	SD	I	D	1	SD	D	D	D	D	D
D14	A	D	A	A	A	I	I	SD	D	SD	D	D	I	1	I	I	D	D	A
D15	A	I	A	A	SD	SD	I	A	I	SD	SD	SD	I	D	1	A	D	D	SA
D16	SA	SA	SA	SA	SA	I	A	A	I	A	A	I	SD	I	I	1	SD	D	D
D17	SA	D	A	A	A	SA	SA	A	SD	SD	I	I	SD	SD	D	D	1	I	A
D18	I	I	A	I	D	SD	A	SA	A	D	A	A	A	I	A	SD	A	1	D
D19	I	A	A	I	I	A	D	SD	SA	A	A	A	I	I	A	SD	I	D	1

Table A2. TFN Values Assigned to a Criterion.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
D1	1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1
D2	0.3, 0.5, 0.7	1	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0, 0.1, 0.3	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.1, 0.3, 0.5
D3	0.5, 0.7, 0.9	0.1, 0.3, 0.5	1	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.3, 0.5, 0.7
D4	0.3, 0.5, 0.7	0, 0.1, 0.3	0.1, 0.3, 0.5	1	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0, 0.1, 0.3	0.5, 0.7, 0.9	0.5, 0.7, 0.9
D5	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0, 0.1, 0.3	1	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.7, 0.9, 1	0.5, 0.7, 0.9
D6	0.7, 0.9, 1	0.5, 0.7, 0.9	0.7, 0.9, 1	0.5, 0.7, 0.9	0.5, 0.7, 0.9	1	0.1, 0.3, 0.5	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0, 0.1, 0.3
D7	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.5, 0.7, 0.9	1	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.3, 0.5, 0.7
D8	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.5, 0.7, 0.9	1	0.5, 0.7, 0.9	0.5, 0.7, 0.9
D9	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0, 0.1, 0.3	0.1, 0.3, 0.5	0.5, 0.7, 0.9	1	0, 0.1, 0.3
D10	0.7, 0.9, 1	0, 0.1, 0.3	0, 0.1, 0.3	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0, 0.1, 0.3	0, 0.1, 0.3	0.5, 0.7, 0.9	0.3, 0.5, 0.7	1
D11	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.7, 0.9, 1	0.7, 0.9, 1	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.7, 0.9, 1	0.5, 0.7, 0.9	0.5, 0.7, 0.9
D12	0.3, 0.5, 0.7	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.5, 0.7, 0.9	0.7, 0.9, 1	0.5, 0.7, 0.9	0.7, 0.9, 1	0.3, 0.5, 0.7	0.3, 0.5, 0.7
D13	0.5, 0.7, 0.9	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.7, 0.9, 1	0.3, 0.5, 0.7	0, 0.1, 0.3
D14	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0, 0.1, 0.3	0.1, 0.3, 0.5	0, 0.1, 0.3
D15	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0, 0.1, 0.3	0, 0.1, 0.3	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0, 0.1, 0.3
D16	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.5, 0.7, 0.9
D17	0.7, 0.9, 1	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.7, 0.9, 1	0.7, 0.9, 1	0.5, 0.7, 0.9	0, 0.1, 0.3	0, 0.1, 0.3
D18	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0, 0.1, 0.3	0.5, 0.7, 0.9	0.7, 0.9, 1	0.5, 0.7, 0.9	0.1, 0.3, 0.5
D19	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0, 0.1, 0.3	0.7, 0.9, 1	0.5, 0.7, 0.9

Table A3. TFN Values Assigned to a Criterion.

	D11	**D12**	**D13**	**D14**	**D15**	**D16**	**D17**	**D18**	**D19**
D1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1
D2	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.7, 0.9, 1	0.5, 0.7, 0.9
D3	0.3, 0.5, 0.7	0, 0.1, 0.3	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.7, 0.9, 1	0.5, 0.7, 0.9
D4	0.5, 0.7, 0.9	0, 0.1, 0.3	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.7, 0.9, 1	0.1, 0.3, 0.5	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.3, 0.5, 0.7
D5	0.7, 0.9, 1	0, 0.1, 0.3	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0, 0.1, 0.3	0, 0.1, 0.3	0, 0.1, 0.3
D6	0.3, 0.5, 0.7	0, 0.1, 0.3	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.1, 0.3, 0.5
D7	0.5, 0.7, 0.9	0, 0.1, 0.3	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.1, 0.3, 0.5	0, 0.1, 0.3	0.5, 0.7, 0.9	0.1, 0.3, 0.5
D8	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.3, 0.5, 0.7	0.7, 0.9, 1	0.7, 0.9, 1	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0.1, 0.3, 0.5
D9	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.7, 0.9, 1	0.7, 0.9, 1	0.7, 0.9, 1	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.7, 0.9, 1	0.5, 0.7, 0.9
D10	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0, 0.1, 0.3	0, 0.1, 0.3	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0.7, 0.9, 1
D11	1	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.1, 0.3, 0.5
D12	0, 0.1, 0.3	1	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.5, 0.7, 0.9	0.7, 0.9, 1	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.3, 0.5, 0.7
D13	0.3, 0.5, 0.7	0.1, 0.3, 0.5	1	0, 0.1, 0.3	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.1, 0.3, 0.5
D14	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.3, 0.5, 0.7	1	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.5, 0.7, 0.9
D15	0, 0.1, 0.3	0, 0.1, 0.3	0.3, 0.5, 0.7	0.1, 0.3, 0.5	1	0.5, 0.7, 0.9	0.1, 0.3, 0.5	0.1, 0.3, 0.5	0.7, 0.9, 1
D16	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0, 0.1, 0.3	0.3, 0.5, 0.7	0.3, 0.5, 0.7	1	0, 0.1, 0.3	0.1, 0.3, 0.5	0.1, 0.3, 0.5
D17	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0, 0.1, 0.3	0, 0.1, 0.3	0.1, 0.3, 0.5	0.1, 0.3, 0.5	1	0.3, 0.5, 0.7	0.5, 0.7, 0.9
D18	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0, 0.1, 0.3	0.5, 0.7, 0.9	1	0.1, 0.3, 0.5
D19	0.5, 0.7, 0.9	0.5, 0.7, 0.9	0.3, 0.5, 0.7	0.3, 0.5, 0.7	0.5, 0.7, 0.9	0, 0.1, 0.3	0.3, 0.5, 0.7	0.1, 0.3, 0.5	1

Table A4. Normalized Direct Matrix.

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19
D1	0.0952	0.0485	0.0408	0.0530	0.0362	0.0474	0.0485	0.0596	0.0529	0.0496	0.0580	0.0451	0.0408	0.0506	0.0524	0.0597	0.0470	0.0540	0.0607
D2	0.0457	0.0960	0.0474	0.0450	0.0373	0.0483	0.0553	0.0562	0.0506	0.0596	0.0491	0.0483	0.0474	0.0453	0.0325	0.0407	0.0403	0.0540	0.0508
D3	0.0469	0.0373	0.0960	0.0461	0.0396	0.0429	0.0428	0.0451	0.0473	0.0506	0.0532	0.0308	0.0540	0.0396	0.0501	0.0308	0.0380	0.0428	0.0450
D4	0.0401	0.0442	0.0386	0.0960	0.0451	0.0508	0.0362	0.0539	0.0485	0.0386	0.0513	0.0406	0.0529	0.0496	0.0403	0.0473	0.0491	0.0374	0.0396
D5	0.0556	0.0329	0.0584	0.0384	0.0960	0.0372	0.0539	0.0358	0.0440	0.0419	0.0467	0.0551	0.0551	0.0409	0.0446	0.0350	0.0402	0.0463	0.0383
D6	0.0512	0.0452	0.0451	0.0294	0.0386	0.0960	0.0508	0.0593	0.0485	0.0541	0.0448	0.0351	0.0374	0.0486	0.0448	0.0563	0.0335	0.0462	0.0496
D7	0.0324	0.0485	0.0441	0.0428	0.0317	0.0483	0.0960	0.0407	0.0485	0.0540	0.0292	0.0451	0.0408	0.0486	0.0501	0.0362	0.0480	0.0541	0.0440
D8	0.0324	0.0497	0.0496	0.0352	0.0419	0.0451	0.0474	0.0949	0.0407	0.0431	0.0513	0.0220	0.0563	0.0508	0.0393	0.0419	0.0426	0.0464	0.0463
D9	0.0481	0.0396	0.0495	0.0341	0.0462	0.0463	0.0397	0.0495	0.0960	0.0352	0.0392	0.0327	0.0508	0.0441	0.0425	0.0418	0.0590	0.0563	0.0529
D10	0.0424	0.0497	0.0585	0.0375	0.0383	0.0452	0.0507	0.0319	0.0295	0.0960	0.0347	0.0340	0.0397	0.0418	0.0324	0.0506	0.0315	0.0329	0.0440
D11	0.0412	0.0552	0.0497	0.0306	0.0263	0.0429	0.0363	0.0528	0.0496	0.0386	0.0952	0.0473	0.0496	0.0428	0.0513	0.0374	0.0368	0.0608	0.0530
D12	0.0447	0.0462	0.0562	0.0529	0.0429	0.0485	0.0462	0.0596	0.0463	0.0408	0.0369	0.0960	0.0298	0.0374	0.0436	0.0495	0.0415	0.0550	0.0474
D13	0.0346	0.0451	0.0485	0.0340	0.0262	0.0452	0.0316	0.0373	0.0395	0.0597	0.0369	0.0306	0.0960	0.0296	0.0457	0.0305	0.0468	0.0406	0.0473
D14	0.0436	0.0418	0.0529	0.0428	0.0384	0.0362	0.0575	0.0384	0.0386	0.0363	0.0315	0.0296	0.0574	0.0960	0.0424	0.0361	0.0580	0.0463	0.0319
D15	0.0468	0.0384	0.0319	0.0338	0.0406	0.0506	0.0529	0.0451	0.0419	0.0607	0.0347	0.0352	0.0464	0.0308	0.0926	0.0329	0.0335	0.0507	0.0332
D16	0.0413	0.0585	0.0396	0.0385	0.0373	0.0309	0.0364	0.0341	0.0552	0.0386	0.0316	0.0496	0.0308	0.0518	0.0336	0.0960	0.0403	0.0442	0.0586
D17	0.0358	0.0373	0.0463	0.0361	0.0395	0.0517	0.0396	0.0507	0.0339	0.0561	0.0502	0.0441	0.0485	0.0418	0.0401	0.0348	0.0952	0.0305	0.0329
D18	0.0422	0.0274	0.0407	0.0383	0.0441	0.0472	0.0485	0.0196	0.0408	0.0463	0.0457	0.0608	0.0518	0.0474	0.0470	0.0496	0.0401	0.0960	0.0508
D19	0.0302	0.0394	0.0419	0.0384	0.0386	0.0330	0.0506	0.0529	0.0386	0.0563	0.0470	0.0484	0.0618	0.0529	0.0425	0.0462	0.0402	0.0386	0.0960

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