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Posted Date: 25 March 2024

doi: 10.20944/preprints202403.1453.v1

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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 logistics is gaining attention due to increased disasters. It involves various operations to support people's survival efforts. Key characteristics include unpredictable demand, sudden large demand volumes, high stakes in delivery timeliness, and limited resources. However, the complexity and unpredictability of disaster scenarios necessitate robust and adaptable performance measurement models to evaluate the effectiveness of sustainable humanitarian relief logistics (SHRL). This study proposes a novel performance measurement model for sustainable humanitarian logistics and supply chains that integrates the Fuzzy Delphi Method (FDM) and Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy-DEMATEL) method. In this research, using 115 articles focused on sustainable humanitarian logistics and supply chains, crisis management, and humanitarian aid, this research identified 25 key performance indicators (KPIs) in the initial phase. Following the implementation of FDM, 19 KPIs were identified as crucial for further analysis. These KPIs were then divided into four distinct categories: "Quality," "Accountability," "Operational Excellence," and "Sustainability". Initially, FDM is utilized to reach a consensus among experts concerning 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 interrelationships among factors, identifying cause-and-effect behavior and ranking them, forming a robust theoretical framework. The study concludes with the development of a comprehensive performance measurement model that facilitates the strategic planning and operational assessment of humanitarian organization operations. The integration of FDM and fuzzy DEMATEL methods offers multiple perspectives for decision-making and helps stakeholders identify critical areas for improvement. Based on the acquired results, the KPIs attached with Quality (P1) aspect of proposed framework has gained significant importance and main cause in cause-and-effect relationship which impacts and 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

1. Introduction

In the last few decades, there has been an enormous increase in the frequency of natural disasters [1,2]. Reviewing records on natural disasters indicates a growing trend in large-scale calamities such as floods, droughts, hurricanes, earthquakes, glacier melting, and various others [1]. According to data from the Centre for Research on the Epidemiology of Disasters [1], from 2000 to 2022, 3852 floods, 282 wildfires, and 2401 storms event occurred, some major disasters such as California experienced 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 Hualapai volcano eruption in January 2022 caused a devastating tsunami, while major hurricanes like Ida, Typhoon Goni, and Cyclone Idai caused widespread destruction [1]. Disasters have a profound impact on people's lives as well as the economy and environment [3]. Table 1 vividly portrays a discernible increase in disaster trends, highlighting escalating patterns and changes in the data from 2000 to 2022 [1]. The escalating influence of disasters, specifically, the quantity 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. EM-DAT from 2000 to 2022 [1].

Disaster Type	No. of Events	Total Deaths	Total Affected Population	Total Damages, Adjusted (Million US$)
Flood	3,852	122,936	1,767,571,036	914.07
Wildfire	282	1,789	14,624,031	130.24
ExtremeTemp.	479	235,480	96,496,219	69.29
Storm	2,401	204,973	801,550,134	1,981.30
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 [4,5]. 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 [6–10]. Furthermore, projections indicate that the frequency of both natural and man-made disasters will experience a fivefold rise within the next 50 years [1,4]. Consequently, humanitarian logistics holds significant importance within disaster management systems. Van Wassenhove [5] argued that eighty percent of total relief cost is for humanitarian logistics alone, which highlights its importance. In literature, the terms "humanitarian logistics", "relief logistics", and "humanitarian supply chain" are frequently used interchangeably [11,12]. Humanitarian Relief Logistics (HRL) plays a vital role in disaster management [13,14]. It also helps the humanitarian organization to achieve their goals [15]. HRL faces challenges in achieving its mission while minimizing environmental impact, managing resources effectively, and ensuring social responsibility [16].

The increasing awareness of environmental and social sustainability issues and their integration into supply chain management contributes to competitiveness [17,18] . In the commercial sector, sustainability has been identified as a significant opportunity for business for the last few decades. In the future, both commercial and humanitarian supply chains will be guided by sustainable development and ecological balance [13]. The focus on sustainability promotes long-term resilience and environmental responsibility, despite challenges in short-lived crisis situations, and there is a growing demand for its integration in humanitarian logistics and supply chains [19–21] . The study suggests that sustainability parameters are not adequately considered in measuring the performance of HRL [22]. Decision makers in the humanitarian sector need to evaluate their decisions' impact on sustainability performance objectives to improve processes and anticipate future impacts [23–25].

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However, the sector's recent incorporation of sustainability in management lacks concrete metrics and tools for measuring performance [26,27]. Multiple authors have advocated for further investigation to incorporate sustainability into the process of making decisions related to humanitarian relief logistics [21,27–29]. 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.

Performance measurement and KPIs play a crucial role in ensuring efficient and effective management of HRL. Humanitarian organizations encounter difficulties in establishing KPIs because of their wide-ranging and complex nature of activities and the different requirements of the stakeholders [27,30]. Blecken [31] reveals 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 [32], location of logistics and emergency centers [33–35], and routing for aid distribution and evacuation [36,37]. The integration of commercial logistics performance measurement metrics cannot be fully replicated in HRL due to the intrinsic attributes of humanitarian relief operations [38,39]. Abidi and Hella [40] emphasized that 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 like cost, quality, time, responsiveness, reliability, and process flexibility [7,41]. Furthermore, sustainability aspects, which encompass economic, environmental, and social factors, are integral to the triple bottom line.

In a nutshell, thus far, HRL managers aim to enhance competitiveness by efficiently managing supply flows and minimizing costs [27]. In accordance with 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 [42]. Considering this requirement, scholarly literature has recognized a deficiency that necessitates the development of a comprehensive framework for establishing KPIs in the realm of SHRL [20]. As HRL is a quite young field and very little work is available in this context in first-quartile journals [43]. MCDM techniques are used by very few authors, Anjomshoae and Ali [44], has conducted a ranking analysis of hierarchically organized key performance indicators in the HSC using Analytic Hierarchy Process (AHP) analysis, and highlighted the importance of performance measurement system in relief chains [44]. Yadav and Barve [25], propose a network framework for different disaster preparedness activities and prioritize these actions by fuzzy ANP. Venkatesh and Zhang [45] developed a framework of 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 to assess SHRL KPIs 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 modelling and literature aspects of this study are as follows:

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- 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, a statistical technique, is effective for categorizing KPIs in the presence of uncertainty. It assists in determining the presence of these KPIs in SHRL or not.
- A strong framework was developed in this study by employing a fuzzy DEMATEL approach to prioritize the identified KPIs by fuzzy Delphi. The primary benefit of fuzzy DEMATEL is its ability to successfully analyse qualitative and quantitative KPIs in the presence of data uncertainty. The fuzzy DEMATEL technique analyses the cause-and-effect behavior and identifies the interdependent relationship 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 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, performance measurement, and the application of the fuzzy Delphi and fuzzy DEMATEL methods. Furthermore, this section presents the identification of KPIs based on a comprehensive literature review.

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 [29]. SHRL is a young field as compared to commercial sustainable logistics, by growing trend of disasters in last few decades researchers and academicians paying attention to this field. Before contextualizing SHRL in detail, disaster, humanitarian logistics, relief activities and sustainability describe and categorized precisely. The word disaster comes in mind with unpredictable destruction and devastation [46]. Disasters, natural or man-made, have a significant impact on society, environment, and individuals [5,12,47–49]. In the past few decades, there has been an increasing trend in these incidents [1,2,50]. The United Nations office for Disaster Risk Reduction [51], and the International Federation of Red Cross and Red Crescent Societies [52] defines disaster as "Disasters are serious disruptions to the functioning of a community that exceed 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 [51]. Disaster relief and continuous aid activities fall under the category of disasters in the context of humanitarian relief [8,53]. Disaster relief involves providing aid to natural disaster, while continuous aid activities encompass aid for developing regions or refugee camps [8].

Effective disaster management is crucial to mitigate these impacts. Van Wassenhove [5] argued that effective disaster management involves preparedness and response, involving human resource selection, knowledge management, operations preparation, financial resource preparation, and collaboration actions. Response relies on preparedness, local conditions, migration activities, and rehabilitation after disaster relief, encompassing core phases. Kovács & Spens [8] 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 [4] also define the 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 for the purpose of alleviating the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking, and tracing, and customs clearance." So, by going through the definition of sustainability, logistics and humanitarian logistics help us to better understand.

The contextualization of sustainable humanitarian relief logistics involves activities not only to save humanity in short-term goals but also in 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 [4]. Conceptualization of sustainability in the context of humanitarian logistics and supply chain is crucial. Robert Engelmen [54] highlights the complexity of sustainability in our current age, encompassing various meanings from environmental improvement to cooling. Sakalasooriya [55] defines sustainability as the equitable, ethical, and efficient use of natural resources to meet the needs of current and future generations while enhancing their wellbeing. Al-Abbadi and Abu Rumman [56] argues 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 wellbeing, and economic prosperity while maintaining accountability to stakeholders [57,58]. we are going to adopt the definitions stated by Al-Abbadi and Abu Rumman [56] and Pojasek's [58] as most relevant in our research context. Sustainable logistics include 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.

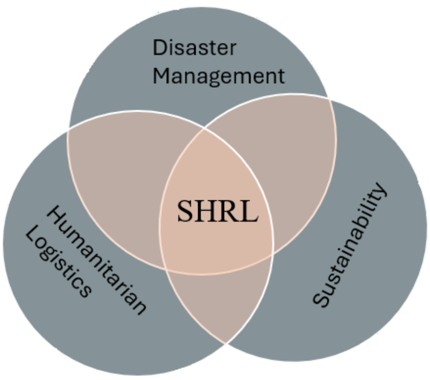

Figure 1. Description of Sustainable Humanitarian Relief Logistics.

Haavisto and Kovács explore sustainability's impact on humanitarian supply chain performance, highlighting its importance alongside efficiency [28]. 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 [59]. The tool uses the TOPSIS method, AHP, and multiplication product to maximize preferences and minimize costs. Cao et al. and Zhang et al. propose multi-objective non-linear 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[60,61]. Dubey and Gunasekaran highlighted the importance of a sustainable humanitarian supply chain, emphasizing agility, adaptability, and alignment [13].

Kempen et al. highlighted the underdevelopment of the triple bottom-line concept in humanitarian aid [62].

Kovács and Spens established the foundation of humanitarian logistics research, highlighting the need to integrate sustainability considerations into logistical activities during disaster relief operations [9]. Jahre et al. [63] 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 need to focus on and demand for new key performance indicator in the context of humanitarian relief logistics and support sustainable practices and sustainability is the key divers to measure the performance of humanitarian organization 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 [64]. It is also worth mentioning here that the term logistics and supply chain are used interchangeably in context of humanitarian operations. Anjomshoae and Banomyong discussed in his literature review that not much research has been done on measuring SHSCM performance yet [20]. 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 [65,66]. Furthermore, the non-profit sector encounters difficulties in assessing performance due to the presence of many objectives [67–69] 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 [70,71]. Lu, Goh et al. [72] developed a performance measurement framework for humanitarian logistics using the supply chain operations reference (SCOR) model, following recommendations from Tatham and Spens [73] and Abidi et al. [74]. Few studies have explored strategic performance measurement concepts like the balanced scorecard for assessing sustainability and efficiency of humanitarian operations [22,75], while Laguna-Salvadzo et al. [27] 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, 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 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 to achieve sustainability goals and satisfy the various humanitarian actors in the field of humanitarian logistics.

In a nutshell, Tatham and Hughes [76] argue that humanitarian organizations (HOs) lack a widely used performance measurement framework, while studies by Lu, Goh et al. [72] and Laguna-Salvadzo et al. [27] highlight the lack of a well-established performance measurement framework, especially when compared to the commercial sector. Existing measures for improving HOs relief operations are results-based, causing uncertainty due to factors beyond one organization's control. Abidi et al. [74] suggests a process-based performance measurement framework and KPIs to address these challenges. Blecken's model, which uses supply chain process modelling to measure HOs performance, is limited to strategic levels and lacks sufficient KPIs to measure performance attributes like reliability and cost across multiple chain levels [31]. Lu, Goh et al. proposed a performance measurement framework using the SCOR model, a comprehensive supply chain process model with pre-made KPIs for commercial world [72]. Guhathakurta [77] and Davidson [78] have both criticised the SCOR for its inflexibility, limited scope, and rigidness of evaluating performance in humanitarian logistics.

Davidson [78] and Beamon and Balcik [79] 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 [66]. 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. 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. Proposed Key Performance Indicators

In this section, all the proposed KPIs are shortlisted with descriptions and sources for further study using MCDM techniques i.e. Fuzzy Delphi and Fuzzy DEMATEL methods.

Performance Measurement is a crucial management tool for assessing work impact, demonstrating value, managing resources, and directing efforts towards improvement. Lambert suggests aligning metrics with organizational goals for optimal performance measurement [80]. Metrics are essential for operational excellence success, providing objective performance measures for programs, activities, systems, and equipment. KPIs are metrics used to measure performance towards strategic and operational objectives of the 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. 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.

Table 2. List of Key Performance Indicators with description and sources.

Sr No	KPIs	Descriptions	Sources
1	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.	[9,12,81–83]

2	Delivery Accuracy	Delivery Accuracy refers to the quality or precision of goods and services, ensuring they accurately match specifications and requirements.	[30,74,81,83,84]
3	Trustworthiness of delivery	Trustworthiness of delivery measures consistency and dependability in terms of quantity, quality, and availability.	[14,85,86]
4	Responsive Delivery	Responsiveness measures flexibility and adaptability to changing needs.	[84,87]
5	Satisfied Delivery	satisfaction measures how satisfied beneficiaries, donors, and humanitarian organizations are with the goods and services provided.	[81,88]
6	Delivery Grievances	An Expression of dissatisfaction. A delivery grievance is a complaint that can be formal.	[89]
7	Delivery Errors	A failed delivery in logistics can occur when there's an error in the shipping address, a human error by the driver, or the driver doesn't meet the required time window	[90,91]
8	Delivery transparency	Delievry Transparency which assesses how accessible the information and communication about the goods and services are to stakeholders and the public.	[87,92]
9	Delivery Participation	Delievry 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.	[81]
10	Delivery Feedback	Feedback should be assessed to determine how effective and responsive the mechanisms for receiving and addressing complaints, suggestions, and compliments are from beneficiaries.	[93,94]
11	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 are from goods and services.	[95,96]
12	Delivery Compliance	Compliance should be surveyed to gauge how well goods and services adhere to relevant laws, regulations, policies, standards, and codes of conduct.	[97,98]
13	Stakeholder Engagement	Stakeholder engagement involves identifying, analyzing, planning, and implementing actions to influence stakeholders, ensuring inclusive and representative participation in planning, implementation, and evaluation of goods and services.	[99]

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14	Resource Utilization	To evaluate resource utilization measures how optimal the use of resources is for goods and services.	[81,82,100]
15	Impact Assessment	Impact assessment measures how well goods and services achieve intended objectives.	[82,101]
16	Adaptive Capacity	Adaptative capacity measures how robust and adaptable goods and services are to cope with shocks.	[100,102]
17	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.	[103–105]
18	Resource Conservation	Resource Conservation measures how waste and degradation of natural resources are from goods and services.	[106,107]
19	Local communities Empowerment	Community empowerment refers to the process of enabling communities to increase control over their lives	[108–110]
20	Labor Condition	How humanitarian organizations take care of the security and working condition and health of their workers in humanitarian relief activities	[111]
21	Political instability	Political instability refers to the probability of a government failing as a result of disagreements or competition among political parties.	[112]
22	logistics dispute and trade dispute	A logistics dispute involves supply chain disagreements, while a trade dispute involves workers and employers, or between countries over products traded.	[113]
23	legislation and regulatory amendments	Logistics legislation and regulatory amendments involves various regulations covering customs, transportation, safety, environmental concerns, and trade agreements, regulated by legislation or Acts of Parliament, and amendments.	[114]
24	Minimize total Cost	Economic impact measures positive effects on income, livelihoods, markets, and infrastructure, while cost minimization reduces unnecessary or inefficient expenditures.	[81,82,115]
25	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.	[82,83,115]

Performance Measurement is a crucial management tool for assessing work impact, demonstrating value, managing resources, and directing efforts towards improvement. Lambert suggests aligning metrics with organizational goals for optimal performance measurement [80]. Metrics are essential for operational excellence success, providing objective performance measures for programs, activities, systems, and equipment. KPIs are metrics used to measure performance

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In this study we identify the KPIs from literature review and expert opinion in this field, and grouped into four categories "Quality", "Accountability", "Operational Excellence", and "Sustainability". These pillars help to improve and monitor the performance of humanitarian organizations and enhance the generated knowledge in the field of relief operations, disaster management, and humanitarian logistics and supply chain. A total of 115 research papers pertaining to sustainable humanitarian logistics, performance measurement, relief operations, humanitarian supply chain were examined, resulting in the identification of 25 KPIs for SHRL.

3. Materials and Methods

3.1. Proposed Framework

Although attempts have been made to encourage varied performance evaluation in humanitarian organizations, there are still certain indicators impeding the progress towards 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. The framework integrates two methodologies and consists of three stages, as shown in Figure 3.

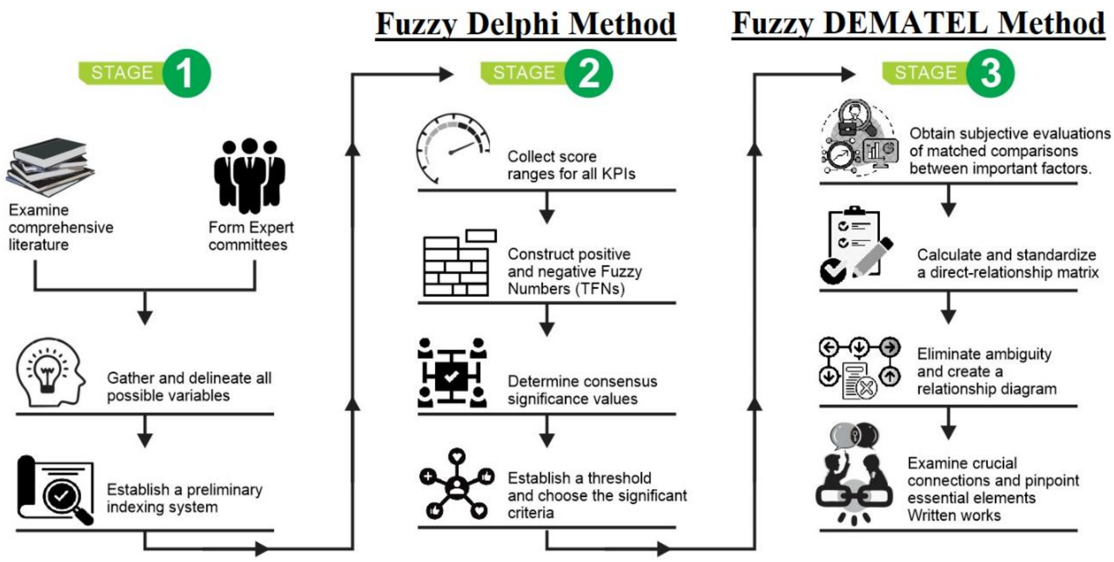

Figure 3. Proposed Framework.

3.1.1. Fuzzy Delphi Method

The Delphi method, developed by Dalky and Helmer in 1963, is a widely used expert opinion communication technique for obtaining anonymous feedback and modifying previous comments. It has been applied in various domains, including industrial quality evaluation[116], investment decisions, production prediction, risk assessment and management, forecasting and trend analysis and disaster preparedness and response. However, the traditional method has deficiencies, such as low convergence ratings, distorted expert opinions, and high execution costs. To address these issues, the fuzzy Delphi method was introduced, allowing decision makers to express their comments through TFNs.

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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, assigning score intervals ranging from 0 to 4, representing their importance. The maximum score interval indicates positive (idealistic) cognition, while the minimum indicates negative (pragmatistic) cognition. This method offers advantages over conventional methods.

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

$$E_m = (x_m, y_m, z_m) \quad (1)$$

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

$$L_m = \left(x_m + y_m + z_m\right)/3 \quad (2)$$

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

(1) If $L_m \geqslant \beta$ accepts criterion m; and

(2) If $L_m < \beta$ omit criterion m.

3.1.2. 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). There are five primary stages of the fuzzy DEMATEL algorithm. The TFNs Strongly agree

Table 3. Linguistic variables and their TFN.

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)

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. 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 $k = 1, 2, 3....p$. Where p denotes the number of respondents. Five stages algorithm for CFCS is given below

Stage 1: Normalization

$$xa_{ij}^k = (a_{ij}^k - \min a_{ij}^k) / \Delta_{\min}^{\max}, \quad (3)$$

$$xb_{ij}^k = (b_{ij}^k - \min a_{ij}^k) / \Delta_{\min}^{\max}, \quad (4)$$

$$xc_{ij}^k = (c_{ij}^k - \min a_{ij}^k) / \Delta_{\min}^{\max}, \quad (5)$$

where $\Delta_{\min}^{\max} = \max c_{ij}^k - \min b_{ij}^k$, (6) Stage 2: Left and right normalized values

$$xls_{ij}^{k} = xb_{ij}^{k} / (1 + xb_{ij}^{k} - xa_{ij}^{k}), \quad (7)$$

$$xcs_{ij}^{k} = xc_{ij}^{k} / (1 + xc_{ij}^{k} - xb_{ij}^{k}) \quad (8)$$

Stage 3: Total normalized crisp value

$$x_{ij}^{k} = \left[xls_{ij}^{k}(1 - xls_{ij}^{k}) + xc_{ij}^{k} \times xc_{ij}^{k} \right] / \left[1 - xls_{ij}^{k} + xcs_{ij}^{k} \right] \quad (9)$$

Stage 4: Crisp value

$$u_{ij}^{k} = \min a_{ij}^{k} + x_{ij}^{k} \Delta_{\min}^{\max}. \quad (10)$$

Stage 5: Combine crisp value

$$u_{ij}^{k} = \frac{1}{p}(u_{ij}^{1} + u_{ij}^{2} + u_{ij}^{3} + \ldots + u_{ij}^{l}). \quad (11)$$

Step 2: Construction of normalized direct relation matrix

The normalizing U matrix calculates the normalized direct relation matrix, such that $M = \left[M_{ij} \right]_{n \times n}$ and $0 \le M_{ij} \le 1$.

The matrix can be calculated by using the following formula:

$$M = \frac{U}{\max_{1 \le i \le n} \sum_{j=1}^{n} u_{ij}}, \quad i, j = 1, 2, 3 \ldots n \quad (12)$$

Where $\max_{1 \le i \le n} \sum_{j=1}^{n} u_{ij}$ denotes the driver having the most influence on other drivers.

Step 3: Finding the total relation matrix

The total relation matrix can be determined by using a normalized matrix.

$$T = M(I - M)^{-1}. \quad (13)$$

Where I denotes the identity matrix.

Step 4: Determining total row and total column values

The following formulas calculate the sum of the entire row (Q) and total column (S)

$$T = \left[t_{ij} \right]_{n \times n} \quad i, j = 1, 2, 3 \ldots n \quad (14)$$

$$Q = \left[\sum_{j=1}^{n} t_{ij} \right]_{n \times 1} \quad (15)$$

$$S = \left[\sum_{i=1}^{n} t_{ij} \right]_{1 \times n} \quad (16)$$

Step 5: Formulation of a cause-and-effect diagram

The sum of Q and S denotes the prominence value, and the difference is the relaxation value. The positive relation value (Q+S) lies in the cause group, and the negative relation value (Q-S) lies in the effect side.

Step 6: The criteria weight calculation formula

$$T_i = \left[(Q_i + S_i)^2 + (Q_i - S_i)^2 \right]^{1/2} \quad (17)$$

$$t_i = \frac{T_i}{\sum_{i=1}^{n} T_i} \quad (18)$$

4. Results

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

4.1. Criteria Selection and Validation 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. (1985) and Ishikawa et al. (1993) 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 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 4.

Table 4. 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 have analyzed literature and reports to identify probable KPIs which are important to measure the performance of HOs. The criteria were divided into four dimensions: Quality, Accountability, Operational Excellence, and Sustainability. The preliminary findings that have been generated as a result of these meetings to form an initial index system for further examination to apply MCDM techniques are described.

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, such as industrialists prioritize efficiency and improvement while buyers assess quality to product perspective and so on. The pursuit of quality is a continuous, iterative process that involves setting clear goals, implementing effective standards, and continuously striving for improvement. Commercial supply chain and logistics is incomplete with quality management in its operations. In humanitarian logistics, where every action can impact lives in desperate need, the pursuit of quality takes on a specific and critical meaning. It's not just about efficiency or cost-effectiveness, but about delivering the right aid, to the right people, at the right time, in the right condition. The following KPIs with their description are included in Quality criteria for proposed PMMSHRL framework.

4.1.2. Accountability (P2):

Accountability is a crucial aspect of ethical behavior, successful relationships, and effective systems. It involves taking responsibility for 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

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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.

4.1.3. Operational Excellence: (P3):

Operational efficiency is a crucial component in achieving success in personal, professional, and academic pursuits. It involves a belief in one's ability to execute actions to achieve specific goals, influencing effectiveness, efficiency, motivation, perseverance, and resilience. It involves a realistic assessment of one's skills, knowledge, and resources, allowing for informed decisions and growth opportunities. Efficacy extends beyond individual capabilities to collective efforts within teams, organizations, and communities. To cultivate efficacy, a supportive environment that encourages learning, experimentation, and feedback is essential. A culture that values perseverance, resilience, and continuous improvement empowers individuals to overcome obstacles and strive for excellence.

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.

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, so 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 5.

Table 5. Fuzzy Delphi Results of KPIs.

Main Criteria	Sub Criteria	Value Results	Accepted/Rejected
Quality (P1)	Prompt Delivery	0.8412	Accepted
	Delivery Accuracy	0.6373	Accepted
	Trustworthiness of delivery	0.9467	Accepted
	Responsive Delivery	0.8092	Accepted
	Satisfied Delivery	0.7515	Accepted
	Delivery Grievances	0.5781	Rejected
	Delivery Errors	0.5591	Rejected
Accountability (P2)	Delivery transparency	0.7018	Accepted
	Delivery Participation	0.6403	Accepted
	Delivery Feedback	0.8275	Accepted
	Capacity Building and Training	0.6567	Accepted
	Delivery Compliance	0.6158	Accepted
	Stakeholder Engagement	0.4367	Rejected
Operatioanl Excellence (P3)	Resource Utilization	0.8586	Accepted
	Impact Assessment	0.7728	Accepted
	Adaptive Capacity	0.6145	Accepted

Sustainability (P4)	Pollution Control	0.6652	Accepted
	Resource Conservation	0.6369	Accepted
	Local communities Empowerment	0.7829	Accepted
	Labor Condition	0.7124	Accepted
	Political instability	0.4231	Rejected
	logistics dispute and trade dispute	0.5694	Rejected
	legislation and regulatory amendments	0.5153	Rejected
	Minimize total Cost	0.7264	Accepted
	Financial Efficiency	0.8586	Accepted

Figure 4 illustrates the findings of Fuzzy Delphi analysis, where 19 KPIs are chosen for further examination using the Fuzzy DEMATEL technique, categorized into four primary groups based on criteria with variable names. The picture illustrates the relative importance and ranking of each criterion used in the Fuzzy DEMATEL approach.

Figure 4. Fuzzy Delphi accepted KPIs with variable names.

4.2. Fuzzy DEMATEL

After FDM and selecting critical KPIs by the expert opinions fuzzy DEMATEL method is applied to get the cause-and-effect relationship among KPIs and establish a structural model.

4.2.1. Making a Pairwise Matrix of KPIs

Participants evaluated each KPI using a five-point linguistic scale. Table 6 displays the outcome of an expert's assessment, illustrating the impact of one KPI on the others. According to the given table Expert argues that D1 has very strong impact (SA) on D2, D3, D4, D6, D10, D16, D17, and D18, medium impact on D5, D8, D9, D11, D12, and D19. He also elaborates that D1 has no impact on D13. Furthermore, D1 has high impact on remaining indicators D7, D14, and D15.

The respondents' reaction, represented as an influence score, is transformed into TFNs. As an illustration, the linguistic variable "Strongly Agree" (SA) with an influence score of 4 is converted into a fuzzy number (0.7, 0.9, 1). The process involves utilizing an excel sheet and implementing the CFCS defuzzification procedure, as described in equations (3) – (11), to transform fuzzy integers into a precise value. The results of the cause-and-effect diagram are calculated by equations 14 to 16 as shown in Figure 5. The results obtained from equation 14 to 16, the values of Q and S form the cause-and-effect diagram. 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

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diagram to describe the KPIs importance and interconnection with each other. From the results (Table 5) we conclude that the prompt delivery D1 is the main factor in the cause group with the highest vertical axis value. 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.

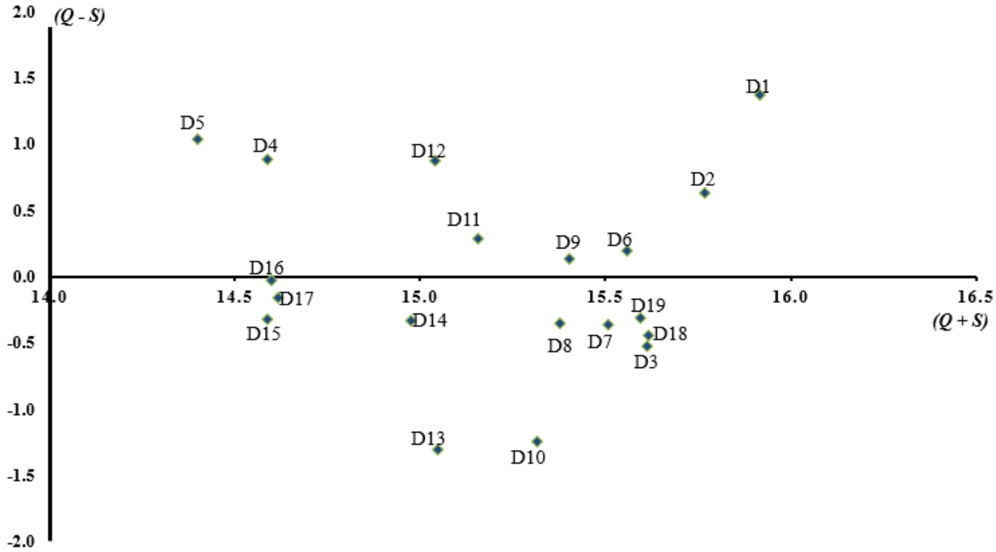

Figure 5. Cause-and-effect diagram of KPIs.

Sustainable humanitarian relief logistics are influenced by several indicators, which were categorized into four groups by experts and intensive literature review and proved by the study that these four groups are essential to measure the performance of HOs. The proposed model and findings reveal that these KPIs are essential to achieve the goals of HOs before, during, and after the disaster and cover all the phases of the disaster management cycle. SHRL's focus is to provide immediate relief to disaster victims to save the lives of people with vulnerabilities as it is its prime responsibility.

Table 6. Final weightage and Ranking for KPIs.

KPIs	Q	S	Q+S	Q-S	Group	Weights	Rank
D1	8.6448	7.2716	15.9164	1.3731	Cause	0.0553	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
D6	7.8740	7.6831	15.5572	0.1909	Cause	0.0538	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
D11	7.7218	7.4333	15.1550	0.2885	Cause	0.0525	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

 doi:10.20944/preprints202403.1453.v1

D14	7.3217	7.6536	14.9753	-0.3319	Effect	0.0518	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

4. Discussion

Performance measurement in the field of humanitarian relief logistics and supply chain management is of utmost importance due to the expanding magnitude and intricacy of natural disasters, diminishing financial assistance from governments, and intensifying rivalry 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 chain.

The study contributes to addressing this gap in SHRL performance measurement. It proposes a scheme for SHRL performance measurement using an integrated Fuzzy Delphi-DEMTAL approach. The results obtained from Fuzzy Delphi-DEMATEL are discussed in this section. The Figure 5 illustrate the cause-and-effect diagram and 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 cause group while trustworthiness of delivery, stakeholder engagement, delivery feedback, delivery compliance, pollution control, resource conservation, local communities empowerment, labor condition, minimize total cost, and financial efficiency falls in effect criteria group. The cause group helps disaster management and humanitarian aid decision-maker 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 first position as its weight is 0.0553, which shows that its impact on whole system of PMMSHRL. The value of Q of D1 in Table 9 is 8.6448, which is also topped ranked in all values of influential group. Hence, D1 has significant impact and influence on other criteria. The criteria "Quality" and its sub KPIs D1, D2, D3, D4, and D5 are crucial for performance measurement of humanitarian organizations to achieve their major goal to survive people in disaster areas. Hence, it proved that these KPIs are vital for the reliability, responsiveness, and satisfaction of relief efforts. They build trust, enable quick response to need, 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 with effectively and efficiently. These KPIs are called quality measures most of the humanitarian organization like sphere develop quality standards to measures the performance of HOs and this empirical analysis with the help of multi criteria decision making models fuzzy Delphi-DEMATEL.

The effect group contained trustworthiness of delivery, stakeholder engagement, delivery feedback, delivery compliance, pollution control, resource conservation, local communities' empowerment, labor condition, minimize total cost, and financial efficiency falls in effect criteria group.

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,

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allocate resources effectively, and enhance their capacity to respond to disasters and support affected communities.

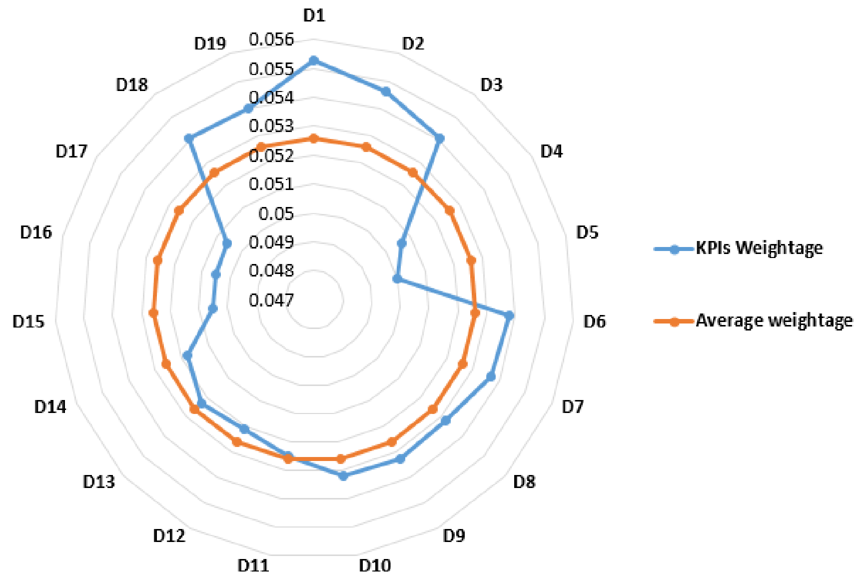

Figure 6. KPIs average weight.

The Fuzzy DEMATEL method is a crucial tool for building cause-and-effect diagram and interrelationship 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, 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. 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 in operational excellence. D11 and D12 are placed in cause group by the calculations which shows that they impact the adaptive capacity. When we take it with whole system and combine with quality measures KPIs we conclude that the 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. While 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, that ultimate and destroy the whole process of SHRL and delaying aid delivery and limiting mitigation measures.

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. It also explores the use of these methods in performance measurement model for sustainable development of humanitarian relief logistics and disaster management. 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.

4.1. Theoretical Implications

The findings suggest theoretical implication of the proposed SHRL framework, it incorporates all the four dimensions of performance measurement such as 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[117]. 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 individual performance metrics without concentrating on several aspects including but not limited to transparency, accountability, quality, efficiency, and sustainability of humanitarian relief logistics. In current research, 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 consolidation of KPIs into comprehensive performance notch through implementing and prioritizing KPIs. Additionally, to improve the uncertainty examination based on the consolidation of KPIs by using of fuzzy Delphi-DEMATEL approach that deal with the ambiguities that are inherent in humanitarian logistics leads to determine the unexpected working conditions. Therefore, the current study will tend to improve the sustainable humanitarian relief logistics by advancing theoretical and empirical performance measurements of fuzzy Delphi-DEMATEL analysis. It also provides the efficiency improvement for measuring diverse humanitarian settings by combining fuzzy logic with established techniques like Delphi and DEMATEL method.

4.2. 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 prioritizing the cause group criteria because they have a significant impact on the effect group criteria[118]. In simple words, 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 as 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 got the highest weight and put topmost in the cause group which means it has significant impact on overall. It demonstrates that the relief goods reach the vulnerable people in stipulated time accurately, then the performance of the whole system is extra ordinary. The effect group KPIs D3, D7, D8, D10, D13, D14, D15, D16, D17, D18, and D19 in which D18 and D19 are ranked in top in effect group. The overall impact of D18 and D19 in whole system is significant. As prompt and accurate delivery guaranteed 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[7,30,82,83]. This is proved through findings that KPIs prompt delivery (D1) and delivery accuracy (D2) have an overall strong impact on complete performance measurement system. Besides, Minimization of total cost (D18) is proven to be of almost equal importance with financial efficiency (D19) criterion. It is crucial to incorporate environmental factors such as pollution control (D14) and resource conservations (D15) into management decision-making to mitigate the adverse environmental effects and fostering sustainable practices in disaster relief operations[55,56].

5. Conclusions

This study provides a comprehensive analysis of drivers that improve humanitarian aid performance for humanitarian organizations. These drivers are significant to measure the performance of HOs. Key performance indicators were identified to help stakeholders like governments, NGOs, donor agencies, beneficiaries effectively overcome the 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, 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, based on the core criteria of "Quality," "Accountability," "Operational Excellence," and "Sustainability." Using the fuzzy DEMATEL method, we were able to determine the cause-and-effect relationship among KPIs. Moreover, the expert groups' evaluations were also conveyed through linguistic ratings and enabling easy calculation of key performance indicators effectively and efficiently.

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. Addressing these challenges requires concerted efforts from stakeholders, including governments, NGOs, UN agencies, private sector partners, and affected communities.

The advancements in disaster management and humanitarian aid delivery will aid enhancing the promptness of future research. Therefore, it will pave the path towards innovations in artificial intelligence, drones, and blockchain technologies. Many stakeholders from diverse sectors may play a critical role and can take advantage from capacity building, running programs and empowering disaster-affected communities for decision making process. Meanwhile, regulatory measure and policy reforms can execute for efficient delivery of aid. Additionally, stakeholder can also take part to improve the outcomes of the disaster management through responsiveness and effectiveness of relief operations, ultimately improving outcomes for disaster-affected populations.

The disaster management and humanitarian relief operation can be improved through artificial intelligence, blockchain management and IoT. It may result to improve the supply chain visibility, streamline logistics and expedite the delivery response. Therefore, these programs may result to strengthen the skills of the relief workers and professionals. In addition to this community centric approaches enable disaster-affected communities to contribute to decision-making processes and relief efforts.

6. Patents

No Patent is registered for this research work.

Supplementary Materials: No Supplementary material is available for this research work.

Author Contributions: Conceptualization, Muhammad Sarfraz Ahmad and Wang Fei; Data curation, Muhammad Sarfraz Ahmad; Formal analysis, Muhammad Sarfraz Ahmad; Investigation, Muhammad Sarfraz Ahmad; Methodology, Muhammad Sarfraz Ahmad, Muhammad Shoaib and Hassan Ali; Resources, Muhammad Sarfraz Ahmad; Software, Muhammad Sarfraz Ahmad and Hassan Ali; Supervision, Wang Fei; Validation, Muhammad Sarfraz Ahmad, Wang Fei and Muhammad Shoaib; Visualization, Muhammad Sarfraz Ahmad; Writing – original draft, Muhammad Sarfraz Ahmad; Writing – review & editing, Muhammad Sarfraz Ahmad. All authors have read and agreed to the published version of the manuscript."

Funding: This research was supported by National Nature Science Foundation of China (No. 41371180).

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

Appendix A

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Table 6. 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 7a. TFNs 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 7b. TFNs 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

 doi:10.20944/preprints202403.1453.v1

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. 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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