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ORIGINAL RESEARCH

A Decision Support Model for Barriers and Optimal Strategy Design in Sustainable Humanitarian Supply Chain Management

Md Maruf Hossan Chowdhury[1] · Sanjoy Kumar Paul[1] · Eijaz Ahmed Khan[2] · A. K. M. Shakil Mahmud[3]

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Abstract *Sustainable humanitarian supply chain (SHSC) management enables effective and efficient responses to natural and human-made disasters. Existing literature falls short of offering decision support (DS) models to address the barriers and strategies to designing SHSC. To this end, this study develops a DS model that identifies and prioritizes the barriers to SHSC and determines optimal strategies for mitigating those barriers. This study adopted both qualitative and quantitative approaches. As part of the qualitative approach, a field study was applied using in-depth interviews to determine the barriers and corresponding strategies, while under the quantitative approach, a quality function deployment (QFD) integrated optimization technique was used to prioritize barriers and determine optimal strategies to mitigate the SHSC barriers. The study found that a lack of contingency planning, the prevalence of corruption and political interference, and a lack of social and environmental awareness are the most important barriers, while logistics outsourcing, supply chain (SC) performance management, and SC flexibility are the most essential strategies. We also found that our DS model is highly flexible and can be adapted under different scenarios, which makes the model applicable to different contexts. This study has a significant contribution to literature and practice. We developed a novel decision model that captured cost savings and leveraged both cost and time savings from interrelated strategies to determine the best optimal strategy while applying QFD-integrated optimization modeling. The paper's findings will assist humanitarian SC managers in designing an effective, efficient, and sustainable humanitarian SC.*

Keywords Flexibility · Humanitarian supply chain · Optimal strategies · Quality function deployment · Sustainability

✉ Md Maruf Hossan Chowdhury
maruf.chowdhury@uts.edu.au

Sanjoy Kumar Paul
sanjoy.paul@uts.edu.au

Eijaz Ahmed Khan
eijaz_2@yahoo.com

A. K. M. Shakil Mahmud
md.shakil1985@gmail.com

[1] UTS Business School, University of Technology Sydney, Sydney, NSW, Australia

[2] College of Business, Law & Governance, James Cook University, Brisbane, QLD, Australia

[3] Department of Business Administration, Hamdard University Bangladesh, Munshiganj, Bangladesh

Introduction

The frequency, severity, and variety of worldwide disasters are on the rise, resulting in millions of casualties and detrimental effects on human lives and natural habitats (Oksuz & Satoglu, 2020). Due to their unpredictable nature, organizations involved in disaster relief operations face numerous challenges when dealing with disasters and crises (Agarwal et al., 2019). Hence, humanitarian supply chains (HSCs) are frequently formed urgently (Modgil et al., 2020). As a result, designing an effective HSC is much more logistically complicated than designing a commercial supply chain (Stewart & Ivanov, 2019). Events such as natural calamities or human-made disasters require immediate and effective action to save human lives without further delay. Holguín-Veras et al. (2012) mentioned that 60% of humanitarian aid does not benefit the victims in disaster areas, which motivates the design of an effective and efficient sustainable humanitarian supply chain (SHSC) program. Furthermore, SHSC faces numerous challenges that thwart successful disaster relief and emergency response operations. Similarly, at the macroeconomic level, humanitarian aid has been criticized for its ineffectiveness (Burnside & Dollar, 2000; Dhillon et al., 2023). Therefore, humanitarian aid and support for disaster-affected people failed to produce the desired results due to the ineffectiveness of sustainable practices. The complexity of the stakeholders (Stewart & Ivanov, 2019), transportation incapacity (Zarei et al., 2019), lack of identification of challenges (Bag et al., 2022; Karuppiah et al., 2021), and adjusting resilience strategies (Xu et al., 2021) are the key reasons why HSCs are not sustainable. Hence, designing an SHSC is imperative for disaster-ridden people to reap the benefits of humanitarian support and to avert the flaws in the supply chain to make it more effective. According to Li et al. (2019), the effective performance of traditional HSCs can be considered sustainable, while Cao et al. (2018) refer to SHSC as integrating HSCs with sustainable performance. Despite calls for research on sustainable humanitarian performance during disasters (e.g., Cao et al., 2021; Dubey & Gunasekaran, 2016; Kunz & Gold, 2017; Li et al., 2019), limited research has been conducted on SHSCs.

Though an SHSC is needed to manage effective and efficient humanitarian aid operations, more empirical research is still required to determine the optimal strategy for SHSC (Cao et al., 2021). The most important aspect is the need for an innovative approach to mitigate the barriers and optimize HSC (Sahebi et al., 2020). In earlier studies, various challenges and strategies have been identified and discussed for SHSC during disasters, but the situation's complexity is not sufficiently explained. For instance, Sabri et al. (2019) identified numerous challenges in the relief activities of SHSC, while Dubey et al. (2019), Ozdemir et al. (2021), and Xu et al. (2021) revealed some strategies for minimizing challenges to SHSC. However, those studies investigate challenges and strategies discretely instead of comprehensively addressing both in a single decision model. Further, the complexity of the decision-making environment, such as the interdependence of strategies, cost of operations, and shortages of resources, is salient factors while taking SHSC design, which is yet to be addressed appropriately. In short, studies have ignored the complex decision-making environment in determining the optimal portfolio of mitigation strategies to mitigate challenges in designing SHSC. However, an oversimplified recommendation suggests that the challenges may exacerbate the problem rather than resolve it by completely disregarding the complex relationships of the challenges, strategies, and decision-making factors, such as the interdependence of strategies, time, and costs of implementing the strategies.

This study aims to fill the above-mentioned gaps by developing a decision support (DS) model, which suggests developing an optimal portfolio of strategies to mitigate the barriers of SHSC by considering the complexity of factors such as resource limitations (e.g., time and budget) and interdependence of challenges and strategies under different scenarios. The study intends to answer the research question: *what is the optimal portfolio of strategies to mitigate barriers by leveraging time and cost in HSC efforts?*

To address the above-mentioned research question, a multi-method and multi-study approach was applied. First, corresponding to objective 1, we identified SHSC challenges and strategies using semi-structured interviews. Second, corresponding to objective 2, the quality function deployment (QFD) technique was used to identify the most important challenges and strategies. Third, corresponding to objective 3, we deployed a nonlinear binary integer optimization approach to determine the optimal portfolio of strategies to mitigate SHSC challenges.

Our study contributes significantly to the literature by developing a novel decision support model for designing an SHSC that identifies, prioritizes, and optimizes a portfolio of strategies to mitigate the challenges of SHSC while considering the complexity of the decision-making environment. The study also offers significant value for managerial decision-making processes. Based on the findings, decision-makers can understand how to mobilize, maneuver, and change an optimal portfolio of solutions in different scenarios and contexts. Crisis management decision-makers will find our model highly flexible and applicable under low to high-time windows and small-to-high monetary budgets. Ultimately, the study will aid supply chain decision-makers in strategizing and designing combat strategies for HSC disruptions, which might need to be responded to quickly with a higher budget and vice versa. Hence, it can help to identify the most cost-efficient and effective strategies to meet such supply chain disruptions. Simultaneously, it can also assist in comparing the most effective strategies for coping with disruptions promptly.

Literature Review

This section discusses the existing studies on SHSC, their barriers, and strategies to overcome them.

Sustainable Humanitarian Supply Chain

HSC involves the supply, distribution, logistics, and delivery activities during natural disasters or emergencies in the affected area; it is also known as the 'relief supply chain' (Seifert et al., 2018). The relief supply chain should be prepared, effective, and responsive to save human lives and distribute relief to the affected people. To ensure the smoothness of operations of HSC, different entities (e.g., suppliers, government bodies, and other stakeholders) need to communicate closely to deliver the activities quickly and efficiently (Gossler et al., 2020). Figure 1 illustrates the supply chain network for an HSC. The concept of SHSC derives from the integration of sustainability and HSC. The overarching philosophy for sustainable development is integrated organically into disaster risk reduction. It includes preventing and mitigating disasters, preparing for them, and distributing relief helps reduce suffering, save lives, and contribute to development, as outlined by the United Nations (2015). Similarly, ensuring the sustainability of HSC requires proper planning, preparation, assurance that specific resources are available, and a certain degree of independence, as Abbas et al. (2021) suggested. Furthermore, Cao et al. (2021) stated that disasters resulting in enormous casualties, property loss, and environmental disturbance harm sustainability. It is reported that 80% of operations are related to logistics in HSC (Li et al., 2019). Thus, to ensure the sustainability of HSC operations, investigating an SHSC requires urgent attention, which is also supported by Abbas et al. (2021), Boostani et al. (2021), Dubey and Gunasekaran (2016), and Karuppiah et al. (2021). However, many barriers impede SHSC operations, while attempts to prioritize and strategies to mitigate these barriers have not been explored extensively. The prioritization of SHSC challenges and strategies is essential because organizations can select appropriate mitigation strategies based on their capabilities.

In humanitarian logistics, the essence of balancing economic, environmental, and social aspects has been discussed in several studies (Abbas et al., 2021; Cao et al., 2018; Kunz & Gold, 2017). Chen et al. (2020) considered sustainable humanitarian operations as a mechanism to decrease vulnerability by addressing immediate needs and developing more resilient and long-term prospects at a minimum cost economically, socially, and environmentally. Cao et al. (2018) emphasized that the inequitable distribution and shortages of supplies contribute to social disturbance, negatively impacting social stability and sustainability from an operational viewpoint. Kunz and Gold (2017) shed light on quick recovery methods from crises while describing SHSC. Haavisto and Kovács (2014) posited that SHSCs should also focus on environmental factors along with economic and social sustainability. Considering these and other examples, the literature has conceptualized SHSC from multiple perspectives. Cao et al., (2017, 2018) defined an SHSC as the integration of sustainable development and HSC. Boostani et al. (2021) considered humanitarian relief supply chains should minimize total costs and maximize social welfare with the least possible environmental impact as their key objectives. Agility and adaptability are key concepts that

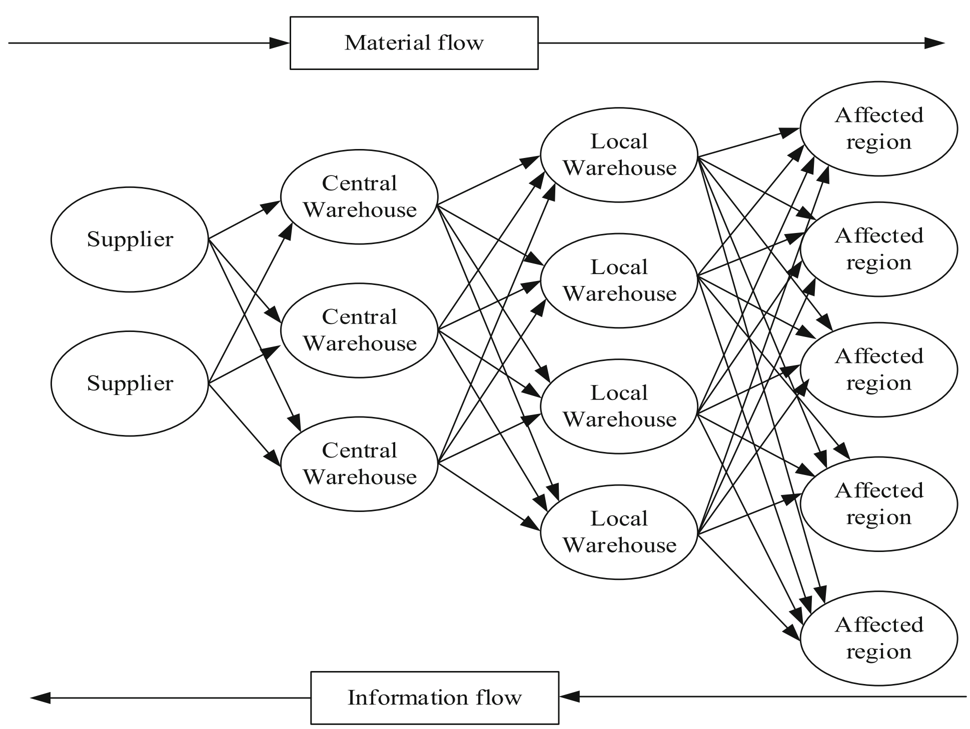


Fig. 1 An overview of HSC (Habib et al., 2016)

deserve attention in the SHSC setting (Dubey & Gunasekaran, 2016). Drawing on the literature (e.g., Boostani et al., 2021; Cao et al., 2017, 2018), in this paper, SHSC is defined as designing HSC operations to deliver the desired emergency relief at the right time and in the correct quantity while optimizing the social, environmental, and economic aspects.

Barriers to Sustainable Humanitarian Supply Chain Management

Rapid and unpredictable occurrences of demand and the prompt delivery of essential relief supplies are exceptional complex features of HSC (Beamon & Balcik, 2008). Oloruntoba (2005) discussed the challenges various humanitarian organizations face during international relief and reconstruction efforts. Such challenges include damage assessments, needs-based assessments, the devastation's scale, funding and donations, logistics, and coordination problems. Furthermore, a significant challenge to implementing humanitarian supply chain management (HSCM) is related to information sharing (Dubey & Gunasekaran, 2016). Lack of proper communication and a manual supply chain approach make the HSC process challenging (Kunz & Gold, 2017). Moreover, the lack of coordination hinders HSCM, resulting in delays in delivering relief materials at the last minute and ineffective response to disaster relief activities (Sahay et al., 2016), which also impedes sustainable humanitarian supply chain management (SHSCM). In addition, HSCM often encounters challenges in controlling its inventory due to the rapid fluctuations in demand (Sentia et al., 2023). Further, inefficient distribution network design—including customer dissatisfaction, longer lead/delivery time, and over or under-utilization of distribution centers—negatively affects supply chain performance (Kunz & Gold, 2017; Sassanelli & Terzi, 2022).

Challenges relating to social and environmental issues substantially impact effective and efficient HSCM processes. Cao et al. (2017) identified carbon emissions, emergency costs, and weighted completion times as significant issues in HSC. Dubey and Gunasekaran (2016) and Karl and Karl (2022) identified some barriers, such as a lack of training and lack of health and safety awareness, as considerable barriers to social sustainability in HSC operations. However, those studies did not prioritize the challenges to guide the decision-makers about the intensity of the barriers and their impact on social, economic, and environmental welfare. Hong and Guo (2019) argue that a lack of environmental awareness hampers the smooth operation of HSC activities. Moreover, failing to engage the local people during relief distribution remains a substantial challenge in humanitarian operations (Abbas et al., 2021). To ensure sustainability, all the stakeholders must play their roles effectively, especially the local people of disaster-ridden areas, whose role remains crucial. However, the literature on humanitarian operations management has been deafeningly silent on optimizing challenges (Salem et al., 2019). As relief products are distributed in remote locations, it is challenging to ensure proper tracking (Fernandez & Suthikarnnarunai, 2017). Transparency in SHSC activities requires agreement from various parties involving government, private, and local stakeholders; otherwise, the lack of transparency impedes the SHSCM process (Dubey & Gunasekaran, 2016). Karuppiah et al. (2021) also identified that the lack of control and monitoring is essential barriers to SHSC. Furthermore, a lack of sense, flexibility, responsiveness, integration, and partnership significantly affects a quick response to the disaster, which impedes the SHSCM process. Moreover, Dubey and Gunasekaran (2016) identified the lack of adaptability to the culture, the lack of collaboration, and the limitations of supply chain partners as substantial inhibitors to the SHSCM process. Despite the numerous challenges to SHSC, the literature does not provide an applied decision support model to confront the barriers to managing operations more seamlessly. Table 1 summarizes the challenges to SHSC.

Strategies for Mitigating Barriers

For efficient and effective HSCM implementation, overcoming the challenges that inhibit successful humanitarian disaster response operations is necessary (Agarwal et al., 2019). Dubey et al. (2014) argue that mitigating HSC challenges is crucial to quickly regaining and restoring normalcy in disaster-prone regions. Considering the severity of the problem related to SHSC, priority-based, widely accepted, and appropriate strategies is imperative for improving humanitarian activities. Practitioners and academicians suggest several strategies instead of any single approach to overcoming HSC barriers (Kabra & Ramesh, 2015b), which is also true for SHSC.

Literature indicates specific strategies for overcoming challenges but lacks strategies for addressing them at different stages of the SHSC. For instance, multiple suppliers and flexible sourcing strategies are critical areas of the procurement process to respond quickly to challenges (Chen et al., 2020). Several researchers have mentioned that flexible transportation strategies, such as an operational mix of transportation and transport availability, effectively distribute relief in the SHSC (Jermsittiparsert & Kampoomprasert, 2019). Similarly, maintaining strategic emergency stocks and encouraging collaboration (cooperation) among supply chain members helps to increase supply chain flexibility, resilience, and agility to mitigate SHSC challenges (Salvadó et al., 2017). Furthermore, to

Table 1 List of barriers to SHSC management

Name of the barrier	References
Lack of information sharing	Dubey and Gunasekaran (2016); Sentia et al. (2023)
Lack of cooperation	Kunz and Gold (2017)
Lack of proper communication	Kunz and Gold (2017); Sentia et al. (2023)
Lack of resource planning and assurance	Abbas et al. (2021)
Ineffective distribution network design	Boostani et al. (2021); Sentia et al. (2023)
Ineffective inventory management	Li et al. (2019); Sentia et al. (2023)
Improper transportation planning	Abbas et al. (2021)
Lack of health and safety awareness	Karl and Karl (2022)
Lack of training	Dubey and Gunasekaran (2016); Yadav and Barve (2016)
Lack of engaging local people	Abbas et al. (2021); Haavisto and Kovács (2014)
Lack of environmental awareness	Karl and Karl (2022); Saïah et al. (2023)
Lack of monitoring	Karuppiah et al. (2021)
Lack of transparency	Dubey and Gunasekaran (2016); Kabra and Ramesh (2015a); Sentia et al. (2023)
Lack of control	Karuppiah et al. (2021)
Lack of sensing	Dubey and Gunasekaran (2016)
Lack of flexibility	Dubey and Gunasekaran (2016)
Lack of responsiveness	Dubey and Gunasekaran (2016)
Lack of adapting to the culture	Dubey and Gunasekaran (2016)
Lack of collaboration	Dubey and Gunasekaran (2016); Sentia et al. (2023)
Limitation of supply chain partners	Dubey and Gunasekaran (2016)

mitigate inventory and transportation-related challenges, several strategies, such as coordination among humanitarian organizations, assisted in increasing efficiencies within disaster relief operations (Dubey & Gunasekaran, 2016). Disaster relief operations are more effective when humanitarian aid organizations coordinate more effectively to deliver relief materials on time (Singh et al., 2018). The prepositioning of relief items efficiently fosters a productive and resilient HSCM (Li et al., 2019). Ineffective inventory management (Li et al., 2019), the lack of information sharing (Dubey & Gunasekaran, 2016), and the lack of resource planning and assurance (Abbas et al., 2021) can be addressed by adopting several strategies such as managing inventory policies, information integration and sharing, and planning emergency activities (e.g., shelter, rehabilitation, and reconstruction) (Bag et al., 2022; Li et al., 2019).

The literature also asserts the importance of outsourcing logistics services to minimize improper transportation planning and delays in distribution (Laguna-Salvadó et al., 2019). Resource sharing has been shown to have a major impact on operational outcomes (Kovács & Tatham, 2009), and decentralized warehouses (Chen et al., 2020) in relief operations and improvements to the relief chain's effectiveness (Patil et al., 2021) could address relief distribution problems. In addition, Kunz and Gold (2017) focus on contingency planning to minimize the HSC crisis. To manage the barriers of SHSC, a learning and innovative culture, particularly through adoption, is essential (Dubey & Gunasekaran, 2016). A summary of strategies for mitigating barriers in SHSC design is presented in Table 2. Though numerous studies focus on strategies to mitigate the barriers of SHSC, an overarching framework to determine optimal strategies to mitigate different barriers is not present.

Methodology

In line with the research objectives, we used qualitative and quantitative methods (Creswell et al., 2003) to develop an empirical DS model to mitigate SHSC barriers by designing suitable strategies. The study concerned Bangladesh, one of the world's most disaster-prone countries, facing severe and frequent humanitarian crises (Mallick et al., 2017). Bangladesh experiences numerous disasters annually, including cyclonic storms, tidal surges, droughts, earthquakes, fires, and floods, affecting millions of people. Bangladesh has made tremendous progress in disaster planning and prevention in recent years, but there is still a lack of infrastructure and institutional support (Ahmed et al., 2016). Moreover, there is a lack of effective policy

Table 2 List of strategies of SHSC

Name of the strategy	Example	References
Flexible manufacturing	Capacity redundancy, resource flexibility	Chen et al. (2020)
Flexible supply chain	Multiple suppliers; flexible sourcing; adaptive supply chain	Kunz and Gold (2017)
Flexible transportation	Operational mix for transportation and availability	Jermsittiparsert and Kampoomprasert (2019)
Strategic stock management	Secure location	Salvadó et al. (2017)
Building relationships with network members	Coordination; adaptability; supplier relations; collaborative procurement; civil-military coordination; commercial-humanitarian cooperation	Dubey and Gunasekaran (2016)
Logistics outsourcing	Emergency sourcing; emergency supply management	Battini et al. (2016); Sentia et al. (2023)
Resource sharing	Social capital; resource sharing with private organizations	Li et al. (2019)
Decentralization	Decentralized warehouse and inventory management	Chen et al. (2020)
Performance management systems	Chain's effectiveness and efficiency	Laguna-Salvadó et al. (2019)
Contingency planning	Enables to react proactively	Kunz and Gold (2017)
Learning and innovativeness culture	Flexibility and control orientation	Dubey and Gunasekaran (2016)

implementation to respond to crises efficiently (Mallick et al., 2017). Thus, an effective SHSC in the context of Bangladesh is needed to save the lives of disaster victims. We developed the DS model in three phases based on a systematic process. Phase 1 adopted the qualitative method, while phases 2 and 3 deployed the quantitative method. Details of each of the three phases are presented below.

Phase 1

In phase 1, we applied a qualitative approach to identify barriers to SHSCM in the literature review and the strategies that would overcome those barriers. Then, we verified those barriers and strategies with the findings from the interviews. Using a semi-structured interview protocol, context-specific data were collected from nine decision-makers involved in sourcing, storing, and distributing humanitarian aid at different operational levels (e.g., local, zonal, and national levels). The participants were asked to describe the barriers to SHSCM (WHATs) and the strategies (HOWs) to overcome the barriers. To collect data, we adhered to the principle of '*[continuation]* until ideas are saturated'. As we noticed no new barriers or strategies emerged from the last two interviews, we stopped interviewing after collecting data from the ninth respondent. The duration of the interview was approximately 30–45 min. Table 3 presents the demographic profile of the respondents.

Interviews were noted, recorded, and transcribed. The content analysis technique was applied to the scripts to analyze the data collected from the interviews. A comparison was conducted between the barriers and strategies outlined in the interviews and those found in the literature, and changes were made as necessary to ensure the content validity of the findings.

Phase 2

In phase 2, we deployed a quantitative approach. Along this line, the importance weights of WHATs were determined (W_i in Fig. 2) using the analytical hierarchy process (AHP) (Saaty & Vargas, 1980). Then, we determined the significance of the strategies using QFD, a tool widely used to translate organizational problems into efficient and effective strategy design (Akao, 1990). In this phase, to determine the importance weights of barriers, we asked the interviewees to compare each SHSC management barrier (WHATs) using a 1–9 point scale (Saaty & Vargas, 1980). The weights of the WHATs thus derived were then used as inputs for QFD (Akao, 1990) to determine the importance of the strategies (HOWs) to mitigate the barriers (see A.I. in Fig. 2). The systematic steps of QFD are illustrated below.

Stage 1: SHSC barriers were identified.

Stage 2: Relative. importance of barriers ($= W_i$) were calculated.

Stage 3: Strategies (HOWs = DR_j) to mitigate the barriers were determined.

Stage 4: Relationships between barriers and strategies (WHAT-HOW relationship) were calculated.

Table 3 Respondent details

Participants	Participant type	Experience (years)	Gender
P1	Government employee (Local)	25	Male
P2	Government employee (National)	15	Female
P3	Supplier	10	Male
P4	Government employee (Local)	18	Male
P5	Logistics provider	08	Male
P6	NGO	10	Male
P7	Supplier	5	Male
P8	Government employee (Zonal)	3	Female
P9	Government employee (National)	12	Male

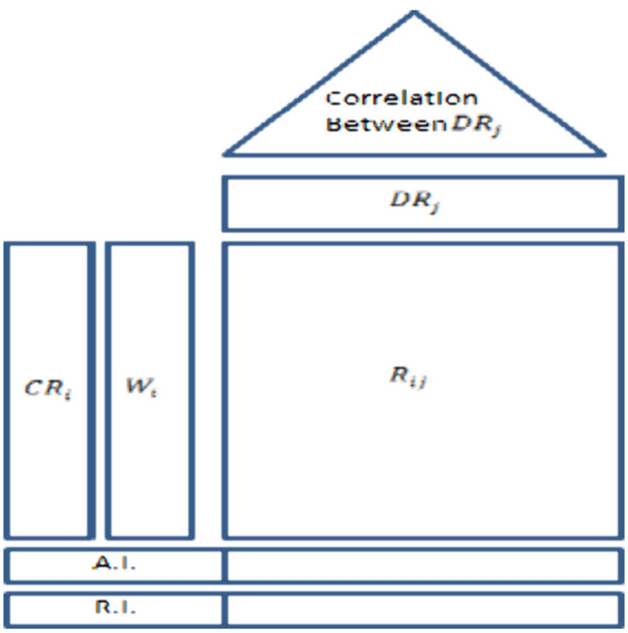


Fig. 2 QFD model. *Note*: CR_i barriers; W_i degree of importance of CR_i's; DR_j design strategies; R_{ij} relationship matrix (i.e., degree to which CR_i is met by DR_j); *AI* absolute importance of DR_j's; *RI* relative importance of DR_j's/strategies

Stage 5: Determining the ranking of strategies based on the barriers and strategies'. relationship. score, weights (A.I. and R.I.) were assigned to the HOWs.

Stage 6: Determining the time and cost savings from the simultaneous implementation of the strategies, relationships between the HOWs were determined.

To. determine. the. relationship between WHAT and HOW, the interviewees were asked to determine the impact of various mitigation strategies (HOWs) to mitigate barriers (WHATs) using the scale. '0 = no', '1 = little', 'moderate = 3', or '9 = strong' (Park & Kim, 1998). The weights represent the relative importance of the relationship. As a result, the following equation determined the importance of each strategy:

$$\mathrm{AI}_j = \sum_{i=1}^{m} w_i R_{ij} \quad \forall_j,\ j = 1,\ldots\ldots,n \tag{1}$$

where AI_j absolute importance of design requirement (DR_j)/strategies, which are also referred to as strategies S_j; W_i weight of the ***i***th barriers which are derived from AHP; R_{ij} relationship value between the *i*th barrier and *j*th strategy (9, 3, 1, or 0); *n* number of strategies; *m* number of barriers.

Similarly, we can determine the relative importance of strategy. *j* using the following equation:

$$\mathrm{RI}_j = \frac{\mathrm{AI}_j}{\sum_{j=1}^{n} \mathrm{AI}_j} \tag{2}$$

where AI_j absolute importance of S_j strategy. $\sum_{j=1}^{n} \mathrm{AI}_j$ summation of the absolute importance of all strategies.

Phase 3

In phase 3, we developed a DS model to identify the.-most.efficient.strategies.to. mitigate the SHSC barriers by using the optimization technique. Our interviewees were asked to discuss the cost and time necessary to implement each. strategy, and the budget required to execute the most important strategies. Additionally, the interviewees were asked whether the simultaneous implementation of strategies would result in cost or time savings.

The optimal strategies were determined by optimizing the absolute importance (AI) values of the strategies within budget and time constraints. For optimization, we utilized nonlinear binary integer programming. The roof matrix shown in Fig. 2 was used to identify the relationships among the strategies to assess the cost and time savings associated with simultaneous implementation. Different symbols indicate the degree of interrelationship between strategies in the roof matrix.

Below is a formula for the optimization problem:

$$\begin{aligned} \text{Max}\, f(x) &= \sum_{j=1}^{n} \text{AI}_j x_j \\ \text{s.t.} \quad & \sum_{j=1}^{n} c_j x_j - \sum_{i=1}^{n} \sum_{j>i}^{n} \text{cs}_{ij} x_i x_j \le \text{budget} \\ & \sum_{j=1}^{n} t_j x_j - \sum_{i=1}^{n} \sum_{j>i}^{n} \text{ts}_{ij} x_i x_j \le \text{time} \\ & x \in X \text{ and } 0, 1. \end{aligned} \tag{3}$$

Application of the Proposed DS Model

In this section, we explain the findings of the three stages of our research, including the application of the DS model for SHSC management in Bangladesh.

Results of Phase 1

Based on the decision-makers' opinions relating to the challenges that impact SHSC management in Bangladesh, we identified a study-specific list of barriers and revised the list identified from the literature review (presented in Table 1) to ensure the context and content validity of our findings. From the interview, we have identified several new barriers, such as the lack of social and environmental awareness, the prevalence of corruption and political interference, the lack of contingency planning, the lack of pre-disaster fund accumulation, the lack of logistical support, and the lack of technological support. The final list of barriers, as obtained from the literature review and interview process, is presented in Table 4.

In this phase, we also identified a list of strategies to mitigate the barriers and revised the list of barriers identified in the literature review (presented in Table 2). From the interviews, we have identified several new strategies, including an increased awareness of health, sanitation, safety, and waste reduction; helping livelihood recovery and alternative income-generating activities; and ensuring the actual needs-based and efficient distribution of relief to the right people. The final list of strategies obtained from the literature review and interviews is presented in Table 5.

Results of Phase 2

In phase 2, we determined the weights of the barriers to SHSC (WHATs) and the importance of strategies (HOWs) to mitigate the barriers. The weights of the barriers to SHSC (WHATs) are shown as Wi in column two of Fig. 3. Then, using the systematic steps of QFD, the absolute importance (AI) value of strategies was derived from the WHAT-HOW relationship matrix (see Fig. 3) to assign weights to strategies and determine the importance of each. We found that strategy S4 (building relationships with network members) had the highest AI value, while strategy S11 (supporting post-disaster livelihood) had the lowest AI value. Additionally, we identified the interrelationships among the strategies/HOWs in this phase, as shown in the roof of Fig. 3. For example, S1 [improving information systems (digitalization)] and S11 (supporting post-disaster livelihood) demonstrated a very strong relationship. Thus, if these strategies are implemented, substantial cost and time savings can be gained. For brevity, we have presented only the relationship strengths in the roof matrix of Fig. 3, while cost and time savings from interrelated strategies are presented in Tables 7 and 8, respectively.

Results of Phase 3

In phase 3, we determined the optimal strategies (HOWs) to mitigate the barriers to SHSC. The objective function refers to maximizing the AI score of each strategy. Through the solution of the optimization problem, we attempted to determine an optimal strategy based on the collected relevant data. Following is the formulation of the optimization problem:

$$\begin{aligned} \text{Max}\, f(x) &= \sum_{j=1}^{n} \text{AI}_j x_j \\ \text{s.t.} \quad & \sum_{j=1}^{n} c_j x_j - \sum_{i=1}^{n} \sum_{j>i}^{n} \text{cs}_{ij} x_i x_j \le \text{budget} \\ & \sum_{j=1}^{n} t_j x_j - \sum_{i=1}^{n} \sum_{j>i}^{n} \text{ts}_{ij} x_i x_j \le \text{time} \\ & x \in X \text{ and } 0, 1. \end{aligned} \tag{3}$$

where $x_j \geq 0$ and $x \in \{0, 1\}$, AI absolute importance scores of the strategies $S_1 \ldots Sj$,$c_j x_j$ the cost of implementing strategies, cs_{ij} cost savings from simultaneous. implementation of strategies, and ts_{ij} time savings from simultaneous implementation of strategies. The values of AI_j, S_{ij}, and C_{ij} are obtained from Fig. 3. In addition, it should be noted that the required cost data C_{ij} and savings data S_{ij} are obtained through interviews with the QFD team.

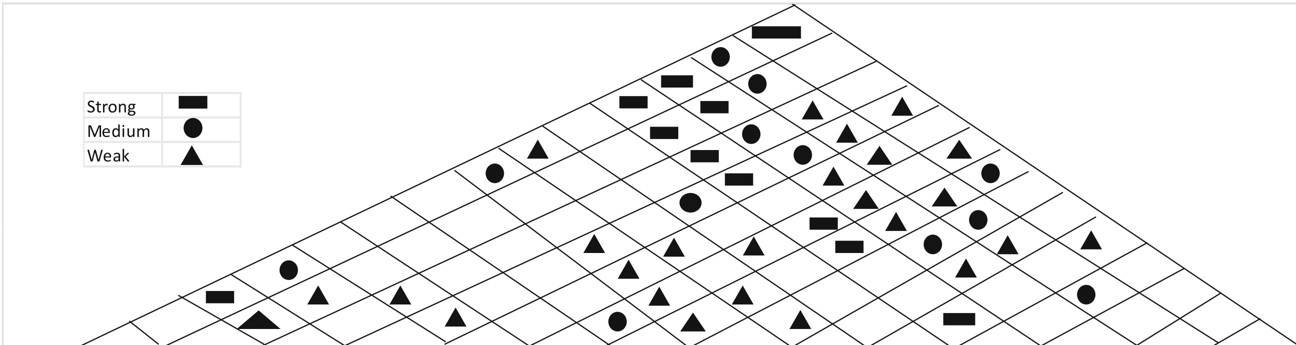
We solved the model using the generalized reduced gradient (GRG) nonlinear solving technique to determine the optimal strategies to mitigate barriers. We used the AI data obtained from the QFD analysis to represent a sample case. The data on implementation time and cost were collected from expert opinions. Table 6 presents the input data.

Table 4 Final list of barriers after the interview

Barrier category	Name of the barrier	Sources
Supply chain operational barrier	Lack of communication and information sharing in the SC network (B1)	Interview + literature review
	Supply problem (quality, quantity, and on-time delivery) (B2)	Interview + literature review
	Lack of planned storage and warehouses (B3)	Interview + literature review
Social and environmental barriers	Lack of health and safety awareness and training (B4)	Interview + literature review
	Lack of stakeholder engagement (engaging local people) (B5)	Interview + literature review
	Lack of social and environmental awareness (B6)	Interview
Governance barrier	Lack of efficient and effective monitoring and control (B7)	Interview + literature review
	Corruption and political interference (B8)	Interview
	Lack of governance and transparency (B9)	Interview + literature review
Agility and adaptability barrier	Lack of contingency planning (B10)	Interview +
	Lack of flexibility (B11)	Interview + literature review
	Lack of responsiveness (B12)	Interview + literature review
Resource barrier	Lack of pre-disaster fund accumulation (B13)	Interview
	Lack of logistical support (B14)	Interview
	Lack of technological support (B15)	Interview

Table 5 List of strategies for HSC

Name of the strategy	Explanation	Sources
Improving Information systems (digitalization) (S1)	Digitalizing records of stock, procurement, distribution, and database to identify ultra-poor and most vulnerable people	Interview + literature review
Improving supply management (S2)	Supply chain planning, determining policy and standards, local procurement for emergency products, supply quality control	Interview + literature review
Improving warehouse management systems (S3)	Distribution facilities, storage	Interview + literature review
Building relationships with network members (S4)	Coordination; adaptability; supplier relations; collaborative procurement; civil–military coordination; commercial–humanitarian cooperation	Interview + literature review
Logistics outsourcing (S5)	Outsourcing during emergency sourcing; emergency supply management	Interview + literature review
Skill development training program (S6)	Staff training and skill development for improving efficiency	Interview + literature review
Social and environmental awareness development campaign (S7)	Improving awareness on health, sanitation, safety, reducing waste	Interview
SC performance management and control (S8)	Setting targets, controlling supply chain management KPIs	Interview + literature review
Contingency planning (S9)	Sensing uncertainties and developing disaster preparedness	Interview + literature review
Engaging multiple stakeholders (S10)	including local people, private sector, NGOs	Interview + literature review
Supporting post-disaster livelihood (S11)	Helping livelihood recovery and alternative income-generating activities	Interview
SC Flexibility (S12)	Procurement and distribution flexibility—multiple suppliers; flexible sourcing, using both own transport and third-party transport for distribution	Interview + literature review
Need assessment and needs-based distribution management (S13)	To ensure actual needs-based and efficient distribution of relief to the right people	Interview
Governance (S14)	Monitoring and governance of relief distribution	Interview + literature review



	St1	St2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
0.020	0	3	0	3	0	0	0	5	0	0	0	3	0	0
0.099	5	0	0	7	0	0	0	3	0	0	0	0	0	0
0.089	7	0	0	5	0	0	0	5	7	0	0	5	0	0
0.089	3	9	5	5	5	0	0	7	7	0	0	7	0	5
0.099	0	0	7	3	7	0	0	7	0	0	0	7	5	5
0.010	7	0	9	0	5	0	0	5	3	0	0	5	0	0
0.099	0	0	0	0	0	7	7	0	0	5	7	0	0	0
0.089	0	0	0	5	0	0	5	0	0	9	0	0	0	0
0.079	0	0	0	0	0	5	9	0	0	5	0	0	0	0
0.040	5	0	0	0	0	0	0	0	0	3	0	0	0	7
0.040	0	0	0	0	0	0	3	0	0	5	0	0	0	5
0.099	7	0	0	0	0	0	3	0	0	5	0	0	0	9
0.079	5	5	5	5	7	5	0	5	9	3	0	7	5	3
0.020	0	0	7	0	9	0	0	5	3	0	0	5	0	0
0.050	0	0	0	0	5	5	0	0	0	0	0	0	0	0
1	**2.743**	**1.257**	**1.762**	**2.782**	**2.168**	**1.733**	**2.267**	**2.703**	**2.050**	**2.743**	**0.693**	**2.525**	**0.891**	**2.545**

Fig. 3 QFD results

Table 6 Strategy implementation time and cost

Strategies														
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
AI	2.048	1.024	2.566	1.650	3.024	1.916	2.048	2.831	1.675	2.205	0.590	2.723	0.723	1.843
Cost	15	4	8	2	4	4	4	4	2	4	20	6	5	5
Time	18	3	6	3	3	3	6	6	3	6	12	6	6	6

There will be some cost and time savings if more than one strategy is implemented. The cost and time savings data are presented in Tables 7 and 8, respectively.

Using the input data, we solved the model to determine the best strategies subject to budgetary and time constraints. In the sample experiment, we considered the maximum implementation budget and time to be US$40 million and 45 months, respectively. Table 9 presents the optimal strategies. We have observed that it would be optimal to implement St2–St10, St12–St14 to gain the maximum benefits of cost and time savings. In this case, the cost and time savings are US$10 million and 21.5 months, respectively.

Further, we have conducted a scenario-based analysis under different implementation budgetary and time constraints. The scenarios are presented in Table 10.

Under different scenarios, we obtained different sets of optimal strategies, as presented in Table 11.

From the scenario analysis presented in Table 11, we observed that the number of strategies in optimal decision-making increased concomitant to an increase in the implementation of budget and time, thus increasing the value of total absolute importance (objective function).

Summary of Results

The results from the qualitative study in *Phase 1* confirmed all the barriers and strategies outlined in the literature (see Tables 4 and 5). The qualitative study also explored several new barriers (e.g., lack of social and environmental awareness) and strategies (e.g., reducing waste; helping livelihood recovery and alternative income-generating

Table 7 Cost savings data

Strategies	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
S1	0	0	1	0.5	0	0	0	0.5	0.2	0	2	1	0.5	1
S2		0	0.2	0.2	0	0	0	0	0	0	1	1	0.5	0
S3			0	0	0.3	0	0	0	0	0	1	0.5	0.2	0
S4				0	0.2	0	0	0.3	0	0.5	1	0.5	0.2	0.2
S5					0	0	0	0.2	0.1	0	0	0.2	0.2	0
S6						0	0.4	0.2	0	0.2	1	0.2	0	0.2
S7							0	0.2	0.1	0	2	0.2	0.2	0.4
S8								0	0.2	0	0	0.5	0.4	0.3
S9									0	0	0	0.2	0.2	0
S10										0	2	0	0.2	0.2
S11											0	0	0.5	0
S12												0	0	0
S13													0	0
S14														0

Table 8 Time savings data

Strategies	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
S1	0	2	1	0.5	0	0	0	1	0	0	2	0	1	1
S2		0	0.5	0.5	0	0	0	0	0	0	1	1	0	0
S3			0	0	0	0.5	0	0.5	0	0	0	1	0	0
S4				0	0.5	0	0	0.5	0	1	1	1	0	0.5
S5					0	0	0	0.5	0.5	0	0	1	1	0
S6						0	1	0.5	0.5	1	1	1	0.5	0.5
S7							0	0	0	0.5	1	0	0	0.5
S8								0	0.5	0	1	1	0	0.5
S9									0	0	0	1	0	0
S10										0	1	0	1	1
S11											0	0	1	0
S12												0	0	0
S13													0	0
S14														0

Table 9 Optimal strategies for the sample experiment

Strategies	St1	St2	St3	St4	St5	St6	St7	St8	St9	St10	St11	St12	St13	St14
Decision	0	1	1	1	1	1	1	1	1	1	0	1	1	1

‘0’ = no; ‘1’ = yes

activities, and ensuring the actual needs-based and efficient distribution of relief to the right people) (for details see Tables 4 and 5).

In *Phase 2*, we found that the lack of contingency planning, the prevalence of corruption and political interference, and lack of social and environmental awareness are the most important barriers, while logistics outsourcing,

Table 10 Scenarios for implementation budget and time

Scenario	Budget (L, M, H)	Time (L, M, H)	Budget	Time
Scenario 1	L	L	15	10
Scenario 2	L	M	15	25
Scenario 3	L	H	15	40
Scenario 4	M	L	30	10
Scenario 5	M	M	30	25
Scenario 6	M	H	30	40
Scenario 7	H	L	45	10
Scenario 8	H	M	45	25
Scenario 9	H	H	45	40

SC performance management, and SC flexibility are the most important strategies. In this phase, Fig. 3 also illustrates the association between the strategies depicted in the roof matrix. For example, S1 [improving information systems (digitalization)] and S11 (supporting post-disaster livelihood) were found to have a very strong relationship. This approach (finding strong correlations among strategies and joint implementation) helps to reduce costs and time substantially. Response and recovery time are crucial elements to a humanitarian crisis, and time-saving is a very important factor along with cost savings in humanitarian SC operations.

In *Phase 3*, the results of the optimization model showed that all except S1 [improving information systems (digitalization)], S11 (supporting post-disaster livelihood), and S12 (SC flexibility) could be implemented within the budget (US$40 million) and time (45 months) to achieve the highest benefits of cost (US$7.9 million) and time (19 months) savings. Moreover, mitigation strategies have the flexibility to tackle different crisis situations, such as the absence of logistical support that requires quick resolution and a higher budget, which may be mitigated by establishing relationships with network members, outsourcing logistics, or developing contingency plans, which is in line with Baharmand et al. (2019). Conversely, improving information systems could mitigate the lack of technological support, communication, and information sharing in an SC network and concur with Jermsittiparsert and Kampoomprasert (2019). In other words, a mitigation strategy can also be applied to several crises, and several strategies can address a problem. In this way, we have performed a scenario-based analysis under various implementations of budgetary and time constraints to determine the most suitable optimal strategies from different sets (see Tables 10 and 11). The analysis addresses dynamic changes in strategies based on changes in situations and offers flexibility to the managers to fit with the context. It also highlights the necessity to investigate key barriers within SHSC and their priorities to enable decision-makers to design effective strategies to achieve the desired outcomes.

Discussion and Implications

This section discusses the theoretical and managerial implications of the study.

Theoretical Implications

Our study provides several theoretical implications. First, using a systematic approach, this study has identified the major barriers to HSC within an emerging economy while designing and implementing a sustainable humanitarian supply chain. It has also systematically prioritized the strategies needed to overcome those barriers. From the theoretical perspective, the study has developed a systematic decision support framework to identify SC barriers and develop strategies using a semi-structured interview, an AHP, a QFD, and a nonlinear binary integer programming

Table 11 Optimal strategies under different scenarios

Scenario	Selected strategies	Objective function
Scenario 1	St4, St5, St9	7.000
Scenario 2	St4, St5, St8, St9, St10	12.446
Scenario 3	St4, St5, St8, St9, St10	12.446
Scenario 4	St4, St5, St9	7.000
Scenario 5	St4, St5, St6, St8, St9, St10, St14	16.724
Scenario 6	St4, St5, St6, St7, St8, St9, St10, St12, St14	21.516
Scenario 7	St4, St5, St9	7.000
Scenario 8	St4, St5, St6, St8, St9, St10, St14	16.724
Scenario 9	St2, St3, St4, St5, St6, St7, St8, St9, St10, St12, St13, St14	25.426

technique, which can be explored, discussed, and expanded for research purposes. According to the study, the most important barriers to achieving SHSC systems and practices include the lack of contingency planning, corruption, political interference, and lack of awareness of social and environmental issues. The study revealed that logistics outsourcing, SC performance management, and SC flexibility are critical to increasing SC capability for efficient SHSC.

Second, there has been a lack of empirical work on this phenomenon in terms of testing SC barriers and their corresponding strategies in designing and implementing an SHSC. By exploring and examining new and existing SC barriers and their corresponding strategies related to SHSC, our study extends the current knowledge in theory and practices on this very important and complex phenomenon and allows future researchers to explore additional factors relating to SHSC barriers and strategies within supply chain management.

Third, our research generates and examines various SC barriers and their corresponding strategies that contribute to optimal strategies for the supply chain in disaster management. In general, in view of supply chain research, and in particular, supply chain disaster management, our method is unique and addresses the void that there is a lack of research in the literature on humanitarian supply chain management to manage extreme disruptions (Thompson and Anderson, 2021). The results of our study advance the literature on supply chain in disaster management related to the SHSC by empirically investigating how to identify and prioritize the barriers, and determine the optimal strategies for mitigating them in order to achieve the desired cost and time performance, which is new in SHSC literature.

Fourth, our research offers an innovative methodological approach in which the qualitative analysis incorporates a field study, and the quantitative analysis uses the QFD-integrated optimization procedure to investigate a complex phenomenon—i.e., the barriers to SHSCM and associated mitigation strategies. Under this approach, our study considered time and cost savings from the interrelated strategies to determine the best optimal strategies. This approach is new and distinct from traditional approaches (e.g., multiple regression analysis and structural equation modeling).

Finally, using a systematic approach, our study has developed an innovative DS model to expound the SHSC nexus, which opens up a new discourse in the supply chain management domain. As a result of this move, we are responding to the call for research to determine optimal strategies for the SHSC to be efficient under the DS model (Dubey et al., 2022; Zanon et al., 2021). Conceptualizing SHSC, along with the application of the QFD-integrated optimization technique, could produce an appropriate optimal strategy; there is limited empirical attention given to this subject in supply chain management to date (e.g., Kaivo-oja et al., 2014).

Managerial Implications

Our study also offers several managerial implications. *First*, the lack of DS modeling among many countries raises questions about the planning and achievement of sustainable performance goals in humanitarian operations (i.e., food, housing, rescue attempts, health, and medical) (Laguna-Salvadó et al., 2019). Identifying and prioritizing barriers and selecting an optimal strategy via our proposed DS model would enable managers to sustainably improve the planning and implementation of HSC processes. Thus, decision-makers can use this information to focus on implementing specific strategies that address critical challenges, leading to more effective and targeted humanitarian supply chain management.

Second, this model can be used by managers from humanitarian organizations to identify HSC barriers and prioritize those barriers in situations where resources are scarce—specifically, organizations that are struggling with cost and time management. Our DS model suggests how to ensure an efficient and sustainable design for humanitarian operations, considering time and cost savings.

Third, the DS model will allow managers to make flexible decisions instead of applying traditional standardized decisions irrespective of a crisis. Such flexible strategies can also be used to examine alternative sets of optimal strategies under various circumstances, which can help increase effectiveness and efficiency. This flexibility is crucial in the unpredictable and dynamic nature of humanitarian crises. As our decision model is highly flexible and adaptable to various scenarios, managers, in this respect, can select the most suitable strategies for overcoming situation-specific challenges. Managers can assess and compare the effectiveness of different strategies in various contexts, resulting in better decisions.

Finally, concerning HSC, most stakeholders (i.e., donors) are interested in whether the operations they support in terms of cost and time have consequential and positive impacts on the affected people (Medina-Borja and Triantis, 2014). Understanding the donor behavior in humanitarian aid operations and educating, assuring, and preparing donors in advance is vital. This is because donors need to know how their contributions will be used effectively and efficiently (Ülkü et al., 2015). Therefore, we argue that our DS model, which aims to identify and prioritize barriers and determine an optimal strategy to implement SHSC processes, also provides valuable information that can be used to attract and motivate potential donors. This would enable designers of HSC management to develop a sustainable approach as a critical success factor.

Conclusions and Future Research Directions

Our study developed a DS model for the SHSC that designs optimal strategies for the supply chain in disaster management. In doing this, we adopted a mixed-method approach, with a qualitative approach that involves field study and a quantitative approach that involves the QFD-integrated optimization technique. The study determined the optimal mitigation strategies by maximizing relative importance while saving cost and time from simultaneous strategy implementations and constrained resources. The analysis method allows one to make accurate decisions and choose optimal strategies.

Our study has several potential limitations. *First*, our DS model allows for finding sustainable alternatives to support humanitarian logistics in terms of cost and time savings. However, the DS model also shows that managers from humanitarian organizations have several intermediate solutions to choose from under different scenarios. All these intermediate choices can be difficult to make in urgent situations. *Second*, our DS model requires a lot of information—(e.g., the relationship between barriers and strategies, cost and time of implementing different strategies) during urgent decision-making processes in a crisis. However, it would be difficult to bring together this information in an HSC context. As such, it could pose a limitation to the application of our model. *Third*, our DS model is developed based on qualitative field study and QFD approach by integrating optimization techniques. Future studies can apply a survey method with a larger sample size and draw statistical inferences to determine the relationship between barriers and strategies and their interdependence. *Fourth*, future research may also focus on a configurational approach such as FsQCA (fuzzy set qualitative comparative analysis) by combining barriers and strategies leading to improvements of SHSC. *Finally*, future research may develop a system dynamic modeling to capture dynamic data and explain SHSC barriers and strategies from a systems behavioral perspective. Using such modeling can also make it possible for decision-makers to simulate how changes to policies and strategies might affect the sustainability of the HSC.

Appendices

Systematic Steps

Stage 1: SHSC barriers were identified

Barrier category	Name of the barrier
Supply chain operational barrier	Lack of communication and information sharing in SC network (B1)
	Supply problem (quality, quantity and on-time delivery) (B2)
	Lack of planned storage and warehouses (B3)
Social and environmental barriers	Lack of health and safety awareness and training (B4)
	Lack of stakeholder engagement (engaging local people) (B5)
	Lack of social and environmental awareness (B6)
Governance barrier	Lack of efficient and effective monitoring and control (B7)
	Corruption and political interference (B8)
	Lack of governance and transparency (B9)
Agility and adaptability barrier	Lack of contingency planning (B10)
	Lack of flexibility (B11)
	Lack of responsiveness (B12)
Resource barrier	Lack of pre-disaster fund accumulation (B13)
	Lack of logistical support (B14)
	Lack of technological support (B15)

Stage 2: Relative importance of barriers (= W_i) were calculated

Barriers													
B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
2.048	1.024	2.567	1.651	3.025	1.916	2.048	2.831	1.675	2.205	0.590	2.723	0.723	1.843

Stage 3: Strategies (HOWs = DR_j) to mitigate the barriers were determined

Name of the strategy
Improving Information systems (digitalization) (S1)
Improving supply management (S2)
Improving warehouse management systems (S3)
Building relationship with network members (S4)
Logistics outsourcing (S5)
Skill development training program (S6)
Social and environmental awareness development campaign (S7)
SC Performance management and control (S8)
Contingency planning (S9)
Engaging multiple stakeholders (S10)
Supporting post-disaster livelihood (S11)
SC Flexibility (S12)
Need assessment and needs-based distribution management (S13)
Governance (S14)

Stage 4a: Relationships between barriers and strategies (WHAT-HOW relationship) were calculated

Barriers	Strategies														
	Weight	St1	St2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
B1	0.02	0	3	0	3	0	0	0	5	0	0	0	3	0	0
B2	0.099	5	0	0	7	0	0	0	3	0	0	0	0	0	0
B3	0.089	7	0	0	5	0	0	0	5	7	0	0	5	0	0
B4	0.089	3	9	5	5	5	0	0	7	7	0	0	7	0	5
B5	0.099	0	0	7	3	7	0	0	7	0	0	0	7	5	5
B6	0.01	7	0	9	0	5	0	0	5	3	0	0	5	0	0
B7	0.099	0	0	0	0	0	7	7	0	0	5	7	0	0	0
B8	0.089	0	0	0	5	0	0	5	0	0	9	0	0	0	0
B9	0.079	0	0	0	0	0	5	9	0	0	5	0	0	0	0
B10	0.04	5	0	0	0	0	0	0	0	0	3	0	0	0	7
B11	0.04	0	0	0	0	0	0	3	0	0	5	0	0	0	5
B12	0.099	7	0	0	0	0	0	3	0	0	5	0	0	0	9
B13	0.079	5	5	5	5	7	5	0	5	9	3	0	7	5	3
B14	0.02	0	0	7	0	9	0	0	5	3	0	0	5	0	0
B15	0.05	0	0	0	0	5	5	0	0	0	0	0	0	0	0
AI	1	**2.743**	**1.257**	**1.762**	**2.782**	**2.168**	**1.733**	**2.267**	**2.703**	**2.05**	**2.743**	**0.693**	**2.525**	**0.891**	**2.545**

Stage 4b: Relationships between barriers and strategies (WHAT-HOW relationship) were calculated

Barriers	Strategies														
	Weight	St1	St2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
B1	0.02	0	0.059	0	0.059	0	0	0	0.099	0	0	0	0.0594	0	0
B2	0.099	0.495	0	0	0.693	0	0	0	0.297	0	0	0	0	0	0
B3	0.089	0.624	0	0	0.446	0	0	0	0.446	0.624	0	0	0.4455	0	0
B4	0.089	0.267	0.802	0.446	0.446	0.446	0	0	0.624	0.624	0	0	0.6238	0	0.446
B5	0.099	0	0	0.693	0.297	0.693	0	0	0.693	0	0	0	0.6931	0.495	0.495
B6	0.01	0.069	0	0.089	0	0.05	0	0	0.05	0.03	0	0	0.0495	0	0
B7	0.099	0	0	0	0	0	0.693	0.693	0	0	0.495	0.693	0	0	0
B8	0.089	0	0	0	0.446	0	0	0.446	0	0	0.802	0	0	0	0
B9	0.079	0	0	0	0	0	0.396	0.713	0	0	0.396	0	0	0	0
B10	0.04	0.198	0	0	0	0	0	0	0	0	0.119	0	0	0	0.277
B11	0.04	0	0	0	0	0	0	0.119	0	0	0.198	0	0	0	0.198
B12	0.099	0.693	0	0	0	0	0	0.297	0	0	0.495	0	0	0	0.891
B13	0.079	0.396	0.396	0.396	0.396	0.554	0.396	0	0.396	0.713	0.238	0	0.5545	0.396	0.238
B14	0.02	0	0	0.139	0	0.178	0	0	0.099	0.059	0	0	0.099	0	0
B15	0.0375	0	0	0	0	0.248	0.248	0	0	0	0	0	0	0	0
AI	1	**2.743**	**1.257**	**1.762**	**2.782**	**2.168**	**1.733**	**2.267**	**2.703**	**2.05**	**2.743**	**0.693**	**2.525**	**0.891**	**2.545**

Stage 5: Determining the ranking of strategies based on the barriers and strategies relationship score.

Table: Cost savings data

Strategies	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
S1	0	0	1	0.5	0	0	0	0.5	0.2	0	2	1	0.5	1
S2		0	0.2	0.2	0	0	0	0	0	0	1	1	0.5	0
S3			0	0	0.3	0	0	0	0	0	1	0.5	0.2	0
S4				0	0.2	0	0	0.3	0	0.5	1	0.5	0.2	0.2
S5					0	0	0	0.2	0.1	0	0	0.2	0.2	0
S6						0	0.4	0.2	0	0.2	1	0.2	0	0.2
S7							0	0.2	0.1	0	2	0.2	0.2	0.4
S8								0	0.2	0	0	0.5	0.4	0.3
S9									0	0	0	0.2	0.2	0
S10										0	2	0	0.2	0.2
S11											0	0	0.5	0
S12												0	0	0
S13													0	0
S14														0

The importance weight of strategies is calculated based on the what and how relationships (step 4). For example, in the relationship matrix the weight of strategy 1 is equal to the sum of the what-how relationships (Fig. 3). Similarly, the importance weight of strategy 2…… St13 has been calculated.

Stage 6: Determining the time and cost savings from the simultaneous implementation of the strategies, relationships between the HOWs were determined.

Table: Time savings data.

Strategies	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
S1	0	2	1	0.5	0	0	0	1	0	0	2	0	1	1
S2		0	0.5	0.5	0	0	0	0	0	0	1	1	0	0
S3			0	0	0	0.5	0	0.5	0	0	0	1	0	0
S4				0	0.5	0	0	0.5	0	1	1	1	0	0.5
S5					0	0	0	0.5	0.5	0	0	1	1	0
S6						0	1	0.5	0.5	1	1	1	0.5	0.5
S7							0	0	0	0.5	1	0	0	0.5
S8								0	0.5	0	1	1	0	0.5
S9									0	0	0	1	0	0
S10										0	1	0	1	1
S11											0	0	1	0
S12												0	0	0
S13													0	0
S14														0

Cost of implementation of each strategy is determined through interview with the managers. Based on the roof matrix, which is the co-relationship of strategies. Moreover, managers' opinion was taken to calculate cost and time savings, which are recorded and presented in following Tables.

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Declarations

Conflict of interest The authors also declare that the author, Sanjoy Kumar Paul, is an Associate Editor of the journal.

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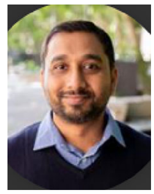
Key Questions

1. What is the optimal portfolio of strategies to mitigate barriers by leveraging time and cost in humanitarian supply chain efforts?



Md Maruf Hossan Chowdhury is currently working as an Associate Professor of operations and supply chain management at UTS Business School. Prior to joining UTS as a lecturer, Dr Chowdhury held academic positions at the University of Western Australia, Curtin University, Australia and Chittagong University, Bangladesh. He has published many articles in the top-tier journals of Operations and Supply Chain Management. His research interest includes supply chain Risk Management, resilience, sustainability, disruptive technologies and their implications on supply chain management.

Sanjoy Kumar Paul is an Associate Professor in Operations and Supply Chain Management at the University of Technology Sydney (UTS), Sydney, Australia. He has published more than 130 papers in top-tier journals and conferences, including European Journal of Operational Research, Transportation Research Part E, International Journal of Production Economics, Business Strategy and the Environment, Computers & Operations Research, Journal of Business Research, International Journal of Production Research, Annals of Operations Research, Journal of Management in Engineering, Journal of Cleaner Production, Computers & Industrial Engineering, Journal of Retailing and Consumer Services, and so on. He is also an editor and active reviewer of many reputed journals. His research interests include supply chain risk management, sustainability, and applied operations research. Dr Paul has received several recognitions and awards in his career, including the top 2% of scientists (three times based on citations in 2020–2022) in author databases of standardized citation indicators, the ASOR Rising Star Award, Excellence in Early Career Research Award, the Stephen Fester prize for most outstanding thesis, and high-impact publications award for publishing articles in top-tier journals.

Eijaz Ahmed Khan is a Senior Lecturer at the College of Business, Law & Governance, James Cook University. He received a PhD from Curtin University, Australia and an MBA from the Asian Institute of Technology, Thailand. Before joining James Cook University, he worked in University of Sydney, University of Technology Sydney, Melbourne Institute of Technology, Asia Pacific International College) and Khulna University. He has published papers in Management Decision, Asia Pacific Journal of Marketing and Logistics, Supply Chain Management: An International Journal, Education and Training, International Journal of Physical Distribution & Logistics Management, Entrepreneurship Research Journal, etc. Currently, he is the Editorial Board Member of the Journal of Management & Organization and Journal of Family Business Management.

A. K. M. Shakil Mahmud is currently working as an Assistant Professor in Department of Business Administration at Hamdard University Bangladesh. Prior to joining Hamdard University Bangladesh as a lecturer, Mr. Mahmud held academic positions in the Dhaka International University, Bangladesh. He has completed BBA and MBA in Marketing from University of Chittagong, Bangladesh. He has published many articles in top-tier journals of Operations and Supply Chain Management including Journal of Physical Distribution & Logistics Management, Asia Pacific Journal of Marketing and Logistics, Management Decision and others. He is also contributing as a reviewer to the top-tier journals of Operations and Supply Chain Management and Tourism. His research interest includes supply chain sustainability, resilience, information integration in supply chain, circular economy.