Global Journal of Flexible Systems Management (March 2025) 26 (Suppl 1):S25–S55
https://doi.org/10.1007/s40171-024-00419-7

ORIGINAL RESEARCH

A Decision Support Framework for Resilient and Sustainable Service Design

Md. Maruf Hossan Chowdhury[1] · Seyed Zeinab Aliahmadi[2] · Mohammed A. Quaddus[3] · Amir H. Ansaripoor[3] · Seyedali Mirjalili[4,5]

Received: 31 October 2023 / Accepted: 15 September 2024 / Published online: 22 October 2024

Abstract *Resilient and sustainable service design is essential for ensuring the longevity and effectiveness of service systems. However, existing literature often neglects key aspects such as articulating resilience attributes and integrating sustainability dimensions. This study proposes a decision support model for a "resilient-sustainable service design" that merges service design principles with resilient system attributes and organizational sustainability goals. The framework incorporates a multi-objective mathematical programming model and a multi-phased Quality Function Deployment (QFD) approach to derive Pareto optimal solutions using the Brute Force algorithm. Applied in the m-health service sector in Bangladesh, the study reveals significant challenges, including limited awareness of services and logistical inefficiencies. To address these issues, flexible strategies such as demand planning and service innovation are implemented. The findings have direct implications for the improvement of service delivery processes and underscore the importance of considering both resilience and sustainability. While focusing on Bangladesh's m-health sector, the insights gained have broader relevance globally. The integration of resilience and sustainability principles into service design is crucial for addressing complex challenges across sectors and regions. Future research could involve longitudinal studies to capture evolving resilience strategies and explore resilient-sustainable service systems from a broader perspective. This entails examining various factors such as technological advancements and socio-economic dynamics shaping resilient and sustainable service ecosystems.*

Keywords Decision support analysis · Flexibelity · QFD · Resilience · Service design · Sustainability · Optimization · Algorithm

✉ Amir H. Ansaripoor
amir.ansaripoor@curtin.edu.au

Md. Maruf Hossan Chowdhury
Maruf.Chowdhury@uts.edu.au

Seyed Zeinab Aliahmadi
seyed-zeinab.aliahmadi.1@ens.etsmtl.ca

Mohammed A. Quaddus
m.quaddus@curtin.edu.au

Seyedali Mirjalili
ali.mirjalili@gmail.com

1 UTS Business School, University of Technology Sydney, Sydney, Australia

2 Department of Systems Engineering, École de Technologie Supérieure, University of Québec, Montréal, Canada

3 School of Management and Marketing, Curtin University, Perth, WA, Australia

4 Center for Artificial Intelligence Research and Optimization, Torrens University Australia, Brisbane, QLD 4006, Australia

5 Department of Computer Science, VSB-Technical University of Ostrava, Ostrava, Czech Republic

Introduction

In recent years, the challenges imposed by rapid technological advancement, increased industrialization, fierce competition and growing demand for materialization, have called for government regulations regarding sustainable and innovative product and service design (Jain & Hazra, 2020; Kumar et al., 2022; Ramandi & Bafruei, 2020; Saha et al., 2022). Sustainable service has been investigated in different contexts. In regard to logistics services, Fulzele et al. (2019) characterized sustainable service systems as processes that are efficient from economic, social, and environmental perspectives. Aliahmadi et al. (2021), also considered the time of logistics activities in addition to addressing the financial concerns of an uncertain service network. However, a system must include various attributes of resilience in order to ensure its long-term sustainability (Ivanov, 2018; Ivanov & Dolgui, 2020). Moreover, a service system must be resilient in order to overcome any disruptions and challenges. There are numerous disruptions and risk factors that can jeopardize the sustainability of a system (Chowdhury & Quaddus, 2021; SadeghZadeh et al., 2023). Hence, a system must be resilient if it is to remain sustainable during perturbation (Derissen et al., 2011; McLellan et al., 2012). Many scholars (e.g., (Ivanov, 2018; Ivanov & Dolgui, 2020; Fiksel, 2006)) have emphasized that a system must be resilient in order to ensure sustainability. Extant literature suggests there are both proactive and reactive approaches to ensuring resilience (e.g., (Ali et al., 2022) and (Aliahmadi et al., 2020)). We contend that a strategy for service design is a proactive means of developing a service system's resilience so as to mitigate the impact of potential disruption. Failure to develop a resilient system can have significant negative impacts on an organization and its supply chain (SC), which can cause financial loss, loss of customers, and business failure (Darzi Ramandi et al., 2023; Pettit et al., 2013). Hence, we posit that a service system needs to be resilient if it is to achieve long-term sustainability. In spite of its huge significance, there is minimal literature on designing a resilient-sustainable service system.

In the domain of service design and product, several concepts are identified in the literature, including customer-oriented design (Hazée et al., 2020), innovative service design (Abdel-Basst et al., 2020), service-oriented design (Traore et al., 2019), co-design and co-production (Freire et al., 2010; O'Brien et al., 2021), product and service system (da Costa Fernandes et al., 2020), eco-design, life cycle design, 'greening' the production systems, and the related initiatives (Keoleian & Menerey, 1994; Ramandi and Bafruei, 2019). Chowdhury and Quaddus (2016) proposed a methodology for a sustainable service design and noted that few of the related studies took an integrated approach. Little attempt has been made to integrate resilience attributes with a sustainable service system, although a system cannot be sustainable without being resilient to disruptions and challenges (Fiksel, 2003, 2006). Yang and Evans (2019) dealt with various archetypes of product-service design and offered a comprehensive framework for sustainable service design. However, the authors did not address resilience issues. Therefore, in mobile health services, creating trust and credibility among the patients is crucial. Chen et al. (2019) mentioned that most of the papers in service systems focus on customer satisfaction at the expense of sustainability concerns. Nevertheless, it is apparent that, to date, no researchers have endeavored to combine these three frameworks. They hypothesize that reconfigurability could be regarded as a comprehensive perspective that unifies research on SC adaptation to constantly evolving environments. Lam et al. (2021) found that the use of IT in health service delivery improves customer satisfaction and quality of service. The authors proposed the incorporation of a new sustainability value-elicitation method within service design. Again, in this work, resilience issues are not taken into account. Negash et al. (2021) developed a hierarchical set of 55 criteria for sustainable service design. The authors mention that these criteria will improve resilience, but do not explain how this will occur. Fiksel (2003) discussed the issues and challenges of a resilient and sustainable system design taking a systems approach and offering a protocol for designing a resilient system. However, the protocol is very general and mostly applicable to "engineered systems". In another study, Fiksel (2006) proposed a dynamic modeling approach for sustainable and resilient systems, although it is not very relevant to service system design. From a holistic perspective, the literature regarding issues of human "mental resilience" (state of well-being, adaptation to hardships) in service systems has also been identified (Anderson & Ostrom, 2015; Chandler & Lusch, 2015; Martin & Hill, 2015) among others.

In this paper, we define the resilience of a service system as its capacity to continue operating during disruptive events that challenge its sustainability. The task of designing a resilient and sustainable service is extremely arduous as service providers need to anticipate a number of challenges that could disrupt the system (Aurich et al., 2010; Sánchez-García et al., 2023) while considering the sustainability of the service system (Beuren et al., 2013). To mitigate such challenges, appropriate strategies with adequate levels of resilience attributes—readiness, response and recovery—need to be adopted alongside strategies for achieving the goals of "people, profit and planet".

The primary challenge addressed in this research is the lack of integrated frameworks that combine resilience and sustainability in service system design. Existing studies focus separately on either sustainability or resilience, but do not adequately integrate both dimensions to address the dynamic and complex nature of service systems. In this regard, the main research objectives that the current study seeks to achieve are presented below.

Research Objectives

- To develop a DSF that integrates resilience and sustainability in service system design.
- To apply the DSF in m-health service settings to demonstrate its practical applicability.

- To identify and prioritize strategies that enhance service resilience and sustainability using a multi-objective optimization model and QFD approach.

From another perspective, complexity is one of the most important issues that can affect the efficiency of an SC. Milgate (2001) investigated the complexity theories toward SC resilience and they concluded that due to increased use of resources, the total complexity level of the SC will increase substantially. This also may lead to more disadvantages than advantages. To deal with this issue and to increase SC resilience, flexible business strategies are utilized by some scholars. Indeed, using flexible business strategies can save resources and encourage the proper utilization of available buffers (Serdarasan, 2013). In the current study, to manage resilient and sustainable service operations, we implemented several flexible strategies such as demand planning, increasing awareness, service innovation, service network integration and better service recovery. However, there is a significant research gap when it comes to a service system design that integrates the resilience dimensions of "*readiness, response and recovery*" (Ponomarov & Holcomb, 2009) and the sustainability goals of "people, profit and planet" (Chowdhury & Quaddus, 2016).

Moreover, in the current study, we applied several flexible strategies including demand planning, increasing awareness, service innovation, service network integration and better service recovery. It is noted that in our model we also draw on the "evolutionary, ambidextrous, multi-faceted process" view proposed by Chae (2012) as well as the principles of service-dominant logic(Vargo and Lusch, 2014). In the following sub-section, we explain the main methodological contributions of our study.

Methodological Contributions

In this study, we propose a multi-objective mathematical programming model integrated with a multi-phased QFD approach, along with a Brute Force algorithm. This methodology was chosen for its ability to prioritize and design strategies effectively. QFD is a widely-accepted tool used for examining the effectiveness of strategies to mitigate challenges, risks, and disruptions. Multi-objective optimization helps determine the most efficient strategies for achieving specific goals (Chowdhury & Quaddus, 2015). The Brute Force algorithm is used to explore all possible solutions exhaustively, ensuring that the optimal strategies are identified.

The rationale for selecting these methods rather than others includes:

- QFD's strength: Its robust framework for prioritizing customer needs and translating them into specific design requirements makes it ideal for integrating resilience and sustainability.
- Multi-objective optimization: This allows for balancing multiple goals, such as cost, time, and sustainability, providing a comprehensive solution.
- Brute Force Algorithm: Although computationally intensive, it guarantees finding the optimal solution by evaluating all possible combinations, ensuring the most resilient and sustainable strategies are selected.

In summary, the first goal of this study is to extend a decision model by identifying the challenges (WHATs) associated with designing a resilient and sustainable service system, and choosing optimal tactics and strategies (HOWs) to address difficulties—all of which are essential for attaining an organization's resilience and sustainability objectives. In line with the research objective, we applied a multi-objective optimization model integrated with a multi-phased QFD approach, which is a widely-accepted tool for prioritizing and designing strategies by examining the effectiveness of strategies to mitigate challenges/risks/disruptions. Therefore, in our study we used QFD to identify those resilience strategies that can effectively overcome existing service design challenges and meet the sustainability goals. As well as QFD, we used multi-objective optimization to determine the most efficient strategies for achieving particular goals (Chowdhury & Quaddus, 2015). Hence, this study makes two noteworthy contributions. First, by integrating resilience terms ('readiness, response and recovery') with sustainability, we propose the 'resilient-sustainable service concept' to develop the traditional 'service concept' and uses the 'evolutionary, ambidextrous, and multifaceted process' perspective and service-dominant logic. Second, our research demonstrates the practical application of the proposed resilient-sustainable service concept through a multi-phase optimization approach based on QFD (discussed in the methodology section) which can be fine-tuned and applied to resolve similar issues.

The reminder of this paper is structured as follows. Section 2 presents the background and literature to position our paper in the context of extant research. The resilient-sustainable service concept is also developed in this section. Section 3 explains the research methodology. In Sect. 4, the application of the developed service design is followed by a real case study in Bangladesh. Section 5 provides a detailed discussion of the theoretical and managerial implications. Finally, Sect. 6 concludes the paper.

Background and Literature

In this section, we provide a comprehensive review of the literature on resilient and sustainable service design, highlighting the challenges faced in this domain and discussing strategies to mitigate these challenges. Service design is a critical aspect of modern business operations, particularly in ensuring resilience and sustainability. Understanding the complexities and dynamics of service design is essential for organizations aiming to deliver high-quality and adaptive services. We begin by exploring the concept of resilient and sustainable service design (Sect. 2.1), followed by an analysis of the challenges inherent in service design (Sect. 2.2), and conclude with a discussion on effective strategies that can be implemented to overcome these challenges (Sect. 2.3). This structured approach aims to provide a comprehensive understanding of the current landscape of service design literature and its implications for practice.

Resilient and Sustainable Service Design

There are various definitions of resilience in the literature (see Chowdhury & Quaddus, 2016). Our study is based on the definitions that are presented by Christopher and Lee (2004) and Ponomarov and Holcomb (2009). According to these papers, a service system's resilience is its ability to develop the required level of readiness, response and recovery when a disruption occurs. Without these elements of resilience, during disruptive events, a service system may fail. Subsequently, this can have significant financial and social impacts which prevent organizations from achieving sustainability. According to Ivanov and Dolgui (2020), a service system should be resilient to have long-term sustainability.

Thus, we expand the concept of 'sustainable service design' proposed by Chowdhury and Quaddus (2016) by introducing the idea of 'resilient and sustainable service design'. In this regard, the most relevant studies are reviewed in this section to acquire a better understanding of the previous attempts made by other scholars. For example, Wang and Yao (2023) introduced a novel integrated supply network system design model. In this model, the network structure was optimized to offer adaptable resilience in response to a dynamic environment Mangla et al. (2014), proposed risk-mitigation strategies and developed a holistic flexible decision framework for green SC. Mohammed (2020) found that both internal and external events can disrupt the performance of a green SC; while most of the current literature considers green and resilience aspects when dealing with selection problems. Since one of the most devastating global occurrences has been the COVID-19 pandemic, in another study, Mohammed et al. (2023) analyzed a dairy manufacturer grappling with disruptions resulting from the pandemic. The focus was on underscoring the significance of cultivating internal capabilities, like preparedness and sensing, to proficiently manage resilience against disruptive external factors. As emphasized, a resilient SC is adept at enduring disruptions arising from both internal and external origins. At that time, Mohammed et al. (2021) also created a comprehensive framework that includes conventional business, green, and resilience criteria along with corresponding sub-criteria.

Moreover, it is worth mentioning that the combination of sustainability and resilience increases the viability of the SC model. According to Ivanov (2021), viability is the capacity of an SC to endure in a dynamic environment by restructuring and re-evaluating performance. The researcher found that the viable SC model can be useful for decision-makers and financial structures of SC are being designed. In this regard, Zekhnini et al. (2022) reviewed numerous papers to determine the connection between lean, green, and sustainability capabilities and their integration into the digital SC. Nasir et al. (2022) examined the relationships among the items influencing the viability of SCs and their achievement of long-term sustainable development goals. A further element of viability considered in the literature is related to the ecosystem. For instance, Ivanov and Dolgui (2020) investigated an integrated supply network consisting of suppliers, focal firms, and market demand after the outbreak of COVID-19. In their subsequent research (Ivanov & Dolgui, 2022), they adopted a human-centered ecosystem viability perspective, integrating aspects of resilience and sustainability. This approach can be applied to SC resilience analysis, especially in the context of prolonged crises like the ongoing pandemic. Additionally, to improve SC viability, Ruel et al. (2021) provided practical guidance and recommendations tailored for practitioners.

According to Ivanov (2024), in addition to the anticipated increase in the amount of literature on SC resilience since 2020, there has been a significant transition from focusing on preparedness and predicting disruptions in pre-pandemic studies to emphasizing recovery and proactive adaptation during and after the pandemic. From the flexibility perspective, Rajesh (2021) investigated five strategies for building resilience in flexible business. He asserted that these strategies are based on reducing any additional complexities. He found that there was a strategic relationship between product, process, and production, along with supply and demand, as different types of flexibilities. In another study,Ahmed et al. (2023) identified and analyzed key strategies for managing flexible sustainable SCs confronted with post-pandemic impacts. On the other hand, Dwivedi et al. (2021) used a survey to determine the challenges in value chain flexibility. A total of thirteen potential challenges were identified and, to tackle these challenges, an integrated model was developed. Mishra et al. (2023) focused on Indian textile SC, as one of the most polluting and demand-urgent industries, encouraging the adoption of circularity by building risk mitigation strategies.

Mishra et al. (2024b) specifically focused on the manufacturing sector and pinpointed six crucial aspects of an agile SC: availability of information, robust design, planning with external resources, speed and responsiveness, skills in influencing public policy, and management of cash flow. Recent research by Chowdhury et al. (2024) explored the role of flexibility in strengthening SC resilience. The researchers developed a resilience capability portfolio aimed at managing severe disruptions, emphasizing the need for adaptable strategies within SCs. This work highlights that flexibility is a critical component of maintaining resilience under extreme conditions. Additionally, Chowdhury et al. (2024) proposed a decision support model to address barriers and to design optimal strategies for sustainable humanitarian SC management. This research identifies key obstacles and proposes strategic solutions to improve the efficiency and sustainability of humanitarian SCs, offering valuable insights into ways of overcoming operational challenges in complex and dynamic environments.

Much of the aforementioned research investigated the impacts of the COVID-19 pandemic on SC efficiency to increase its flexibility and resiliency, like Haji and Himpel (2024), Piila and Sarja (2024), and Villar et al. (2024). Specifically, Leite and Hodgkinson (2023) examined the impact of increasing infection rates and heightened pressure on healthcare systems to understand how initial resilience was activated throughout the service ecosystem. Using qualitative data from various healthcare stakeholders, the researchers employed a significant focus. However, in today's unstable world, there are many more issues that need to be considered. For example, Mishra et al. (2024a) noted that the Ukraine-Russia conflict has disrupted Eastern European SCs, causing delays and increased costs, with security concerns and Western sanctions adding further challenges.

Recent studies have continued to explore and expand upon the themes of resilience and sustainability in service design. For instance, Smith and Brown (2023) introduced a framework for adaptive service design, emphasizing the importance of agility and rapid response mechanisms in service systems. This work highlights the need for continuous monitoring and adjustment to maintain service quality in changing environments. Similarly, Biswas et al. (2023) and Johnson and Lee (2023) proposed integrated approaches to service design that combines digital transformation with sustainable practices, demonstrating how technology can be leveraged to strengthen both resilience and sustainability. Moreover, Taylor and Kim (2023) conducted a comprehensive analysis of post-pandemic service strategies, identifying key factors that contribute to resilient service delivery in various sectors, including healthcare and logistics. Collectively, these studies demonstrate the evolving nature of service design, calling for a more dynamic and holistic approach to address contemporary challenges.

To specifically introduce the proposed 'resilient-sustainable service concept' of our study, several of the main concepts based on the reviewed literature need to be discussed. Goldstein et al. (2002) defined the service concept, in terms of the WHATs and HOWs of service design, while also ensuring integration between them. Chowdhury and Quaddus (2016) however, concluded contextual WHATs and HOWs depending on particular service types and contexts. In their research, the WHATs are the obstacles in connecting with customers for the service, while the HOWs refer to strategies designed to overcome these barriers to achieve the organization's sustainability objectives. According to these two main studies, our framework of resilient-sustainable service concept is generally adapted from Chowdhury and Quaddus (2016) and Goldstein et al. (2002). The WHATs in our study are the quality service design challenges and the HOWs are the strategies to mitigate the challenges, in line with the resilience and sustainability objectives of the organization. To provide a comprehensive understanding of the recent scholarly attempts, we review the most relevant studies in Table 1.

Figure 1 presents our "resilient-sustainable service concept". It is suggested that firms need to identify any service design challenges (WHATs) in order to develop service design strategies (HOWs) that have resilience attributes, including readiness, response and recovery, as well as the sustainability attributes, including people, planet and profit. Thus, the strategies for implementation, referred to as HOWs, are identified based on various resilience strategies that should also demonstrate a high likelihood of accomplishing the organization's sustainability objectives. As a result, service delivery strategies seamlessly incorporate both resilience attributes and the organizations' sustainability goals to address challenges in service design (WHATs). Importantly, the implementation of HOWs requires various resources (tangible and intangible) as well as support from customers and other stakeholders.

Indeed, between WHATs and HOWs there is a feedback loop that supports the "evolutionary, ambidextrous, multifaceted process", which requires continuous improvement of the WHATs and HOWs. So, the service outcomes (customer satisfaction and experiences) must be invited to

Table 1 Summary of key contributions in resilient and sustainable service design

Study	Main contribution	Context/findings
Chowdhury and Quaddus (2016)	Sustainable service design	Contextual WHATs and HOWs
Mohammed (2020)	Impact of disruptions on green SC	Internal and external event impacts
Ivanov and Dolgui (2020)	Post-COVID integrated supply network	Human-centered ecosystem viability
Mohammed et al. (2021)	Comprehensive resilience framework	Green and resilience criteria
Ivanov (2021)	Viable SC model	Restructuring performance
Rajesh (2021)	Resilience strategies in flexible business	Reducing complexities
Dwivedi et al. (2021)	Value chain flexibility challenges	Identified potential challenges
Zekhnini et al. (2022)	Lean, green, and sustainability integration	Digital SC integration
Nasir et al. (2022)	Viability and sustainability goals	Relationships among viability factors
Wang and Yao (2023)	Integrated supply network design	Adaptable network structure
Mohammed et al. (2023)	COVID-19 impact analysis	Preparedness and sensing capabilities
Leite and Hodgkinson (2023)	Healthcare resilience during COVID-19	Initial resilience activation
Ahmed et al. (2023)	Flexible SC strategies	Post-COVID-19 impacts
Mishra et al. (2023)	Circularity in Indian textile SC	Risk mitigation strategies
Gupta et al. (2024)	Enhanced SC strategic model	Leanness, agility, and resilience
Chowdhury et al. (2024)	Resilience capability portfolio	Enhancing SC resilience during severe disruption
Mishra et al. (2024a)	Ukraine-Russia conflict impact	Disruption and increased costs
Ivanov (2024)	SC resilience literature shift	From preparedness to recovery
Haji and Himpel (2024), Piila and Sarja (2024), Villar et al. (2024)	COVID-19 SC efficiency impact	Increased flexibility and resiliency
This Study	Resilient-sustainable service design framework	Integrated resilience and sustainability attributes using a multi-objective model, QFD approach, and Brute Force algorithm for optimal strategies

provide feedback that will inform the revision or expansion of the WHATs. Our model also supports the "evolutionary, ambidextrous, multifaceted process" of Chae (2012) via its feedback loop, which calls for ongoing enhancement of the WHATs and HOWs. Therefore, it aligns with the service innovation features of Chae (2012) and organizations' response to the dynamic nature of environmental changes (Chowdhury et al., 2019; Teece, 2007). In this regard, our resilient-sustainable service model is process-oriented and requires the involvement of customers as well as various other stakeholders. Generally, our introduced framework presents a dynamic service design model that is flexible and sustainable.

Challenges to Service Design

Limited research has been undertaken on the difficulties linked with designing services. The majority of the research concentrates on the challenges related to service quality, which, in reality, are connected to the challenges of

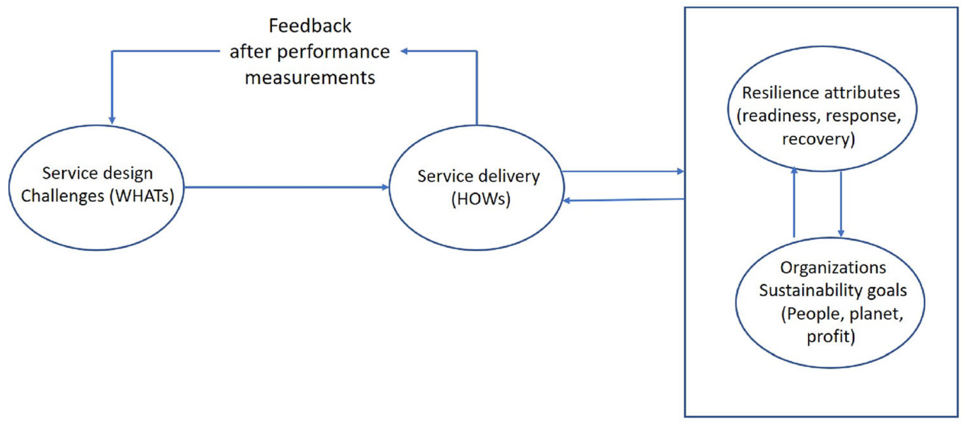


Fig. 1 The framework of resilient-sustainable service concept (adapted from Chowdhury and Quaddus (2016) and Goldstein et al. (2002)

designing quality services. Gerstner and Libai (2006) reported that lack of training, service process failures, inadequate choice of personnel, and misalignment of incentives, are the major challenges that need to be overcome to ensure service quality. Newman (2001) found that inadequate communication and lack of top management commitment are the main challenges facing service design, while Burke (2001) found that lack of management control compromises the service quality. Some of the studies investigated challenges in sustainable design such as cost (Chowdhury & Quaddus, 2016; Travis et al., 2004), inadequate information flow and lack of feedback ((Chou et al., 2012);(Chowdhury & Quaddus, 2016)), shortage of skilled employees and lack of incentives (Chowdhury & Quaddus, 2016). These service design issues create disruptions in the service delivery process.

Strategies to Mitigate Service Design Challenges

As mentioned earlier, effective and efficient service design is challenging due to the presence of many disruptive factors. Therefore, to ensure effective service design, it is crucial to devise strategies that can identify and mitigate these factors. In order to implement such strategies, decision-makers need to carefully decide on the suitability of proposed strategies and the resources required for implementation. While most of the studies in service marketing literature focus on the strategies for improving service quality, very few consider strategies for addressing service design challenges. Becker et al. (2010) discussed several strategies such as early customer engagement in the service design phase; ways of improving relationships between the service provider and the receiver; improving technologies, logistical support, and the training of employees, all of which can mitigate challenges of sustainable product and service design. Nonetheless, these studies do not incorporate the resilience attributes required to mitigate the challenges and, as a result, this mitigation might not be sustained. Therefore, managers must include resilience attributes in the design of such strategies. However, as mentioned above, they also need to be contextualized for any specific application.

Methodology

Consistent with Bolton and Lemon (1999), we recognize the systems of service exhibit dynamism, given that customers' service needs and utilization evolve over time. In line with Chowdhury and Quaddus (2016), Fig. 1 above

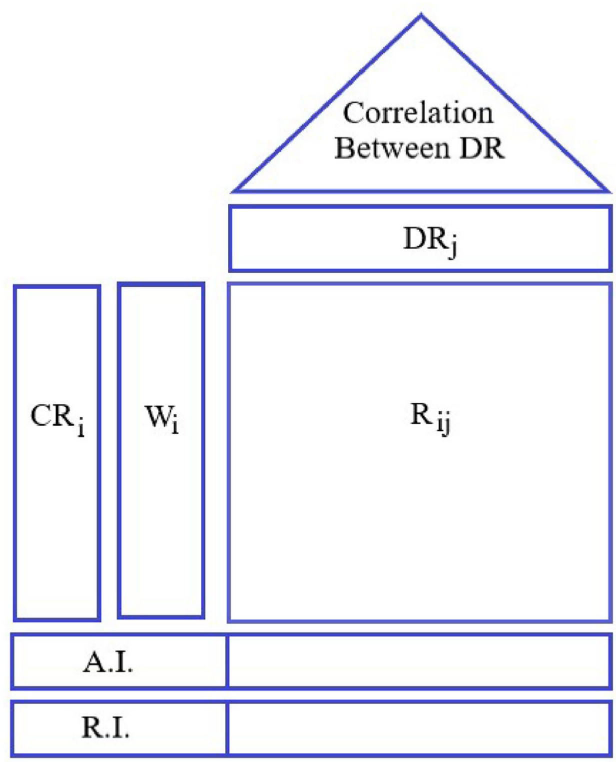


Fig. 2 QFD Framework

depicts the QFD approach and Fig. 2 presents the typical QFD framework. As QFD starts with explicating customer needs, the scheme of QFD fits well with that of the resilient sustainable service concept (cf. Fig. 2). The QFD is considered to be an effective method of designing organizational strategies as it incorporates the voice of the customers in order to achieve organizational goals (Akao, 1990; Chan & Wu, 2002b). The QFD has also been used to design of service systems. For example, Wolniak and Sedek (2009) used it for the ecological design of products.

To define the notations used in Fig. 2, it is generally termed the 'roof matrix' in the QFD literature and shows the correlation between strategies. DR_j is the design requirement of the j-th resilience strategy in which the correlation between the values of DR_j (strategies/HOWs) plays a substantial role in many QFD-based studies, including this study. CR_i is the customer requirement of the i-th service design challenge and W_i is the weight of CR_i. R_{ij} is the relationship value of the i-th service design challenge and the j-th resilience strategy. AI_j is the total resilience of the j-th resilience strategy for mitigating the challenges and RI_j is relative importance of the HOWs (j-th resilience strategy).

In the current study, consistent with our 'resilient-sustainable service concept' (Fig. 2) we utilize a multi-phased QFD approach (Dai & Blackhurst, 2012; Hauser et al., 1988) to extend a DSF, which is based on a multi-objective optimization model for resilient-sustainable service design. The multi-objective-integrated, multi-phased QFD approach of our study is shown in Fig. 3.

Phase 1: In the first phase, we identify issues that disrupt the service process and then score them according to their importance. These issues are the WHATs; i.e., CR_i in QFD matrix as shown in Fig. 2. To determine the weights of WHATs (W_i's, cf. Fig. 2) we utilize the AHP. Based on the score derived from the AHP, we determine the most important challenges and use those in a QFD matrix. Corresponding to the challenges, in this phase, we identify the resilience strategies (HOWs). We also establish the

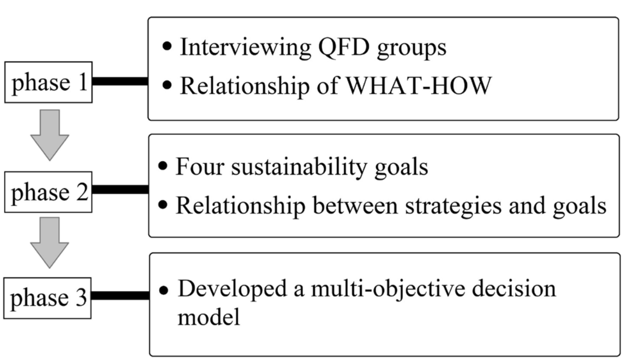


Fig. 3 The main three phases of the results

connection between the challenges and strategies for resilience (R_{ij}). In line with previous studies on QFD (Chan & Wu, 2002a; Faisal, 2013; Nyoman Pujawan & Geraldin, 2009) we measure R_{ij} using the scale 0, 1, 3, and 9, where indicate no, little, moderate, and strong mitigations, respectively. The A.I. and R.I. in Fig. 2 are calculated using equations (1) and (2), respectively (Park & Kim, 1998):

$$AI_j = \sum_{i=1}^{m} W_i R_{ij} \quad \forall j = \{1, 2, \ldots, n\} \tag{1}$$

$$RI_j = \frac{AI_j}{\sum_{h=1}^{n} AI_h} \quad \forall j = \{1, 2, \ldots, n\} \tag{2}$$

The literature suggests that in the actual application, strategies usually have some degree of interdependencies(Park & Kim, 1998; Wasserman, 1993). Moreover, if the two strategies (HOWi and HOWj) are correlated, there are cost savings S_{ij} in implementing them (Park & Kim, 1998). In this paper, we argue that the simultaneous implementation of two correlated strategies (HOWi and HOWj) will result in time-saving t_{ij}. We also argue that time is an important constraint that ensures the resilience and sustainability of any system. The values of S_{ij}'s and t_{ij}'s are established by the decision-makers/QFD team and are presented in Appendix A and B. All of the applied parameters are listed in Table 2.

Phase 2: In this phase, we investigate sustainability objectives following consultations with the QFD team. We then determine the influence of resilience strategies in term of realizing the sustainability goals. Thus, in the second phase, the WHATs are the sustainability goals and the HOWs are the resilience strategies derived from the first phase. Following Eq. (1) and (2), we determine the values of AI_j and the RI_j for each resilience strategy relating to the sustainability goals. This step allows us to determine whether the important resilience strategies corresponding to the service design challenges (derived from Phase 1) can help to achieve sustainability goals. Once the sustainability scores of the resilience strategies (i.e., $RES_j, j \in \{1, \ldots, n\}$) have been determined, the next step involves finding the most efficient strategies for implementation.

Phase 3: In the third phase, we use a multi-objective optimization approach to identify the most efficient resilience strategies corresponding to the sustainability goals. In this study, we follow the procedure of Chowdhury and Quaddus (2015) to obtain the most efficient strategies. Moreover, we extend the work of Chowdhury and Quaddus (2015) by considering the time factor and the cost as important determinants of resilience strategies. We posit that a resilient service design and delivery must consider the time factor, as the failure to develop the capacity for readiness and timely response will increase vulnerability

Table 2 Parameters definition

Parameters	Definition
CR_i	Customer requirement of the i-th service design challenge, $\forall i = \{1, 2, ..., m\}$.
DR_j	Design requirement of the j-th resilience strategy, $\forall j = \{1, 2, ..., n\}$.
AI_j	Absolute importance of DR_j, $\forall j = \{1, 2, ..., n\}$.
RI_j	Relative importance vector of DR_j, $\forall j = \{1, 2, ..., n\}$.
RES_j	Resilience-sustainability score from the j-th resilience strategy relating to readiness, response and recovery, $\forall j = \{1, 2, ..., n\}$.
W_i	Weight of CR_i, $\forall i = \{1, 2, ..., m\}$.
R_{ij}	The relationship value of the i-th service design challenge and the j-th resilience strategy defined aforementioned $\forall i = \{1, 2, ..., m\}$, $\forall j = \{1, 2, ..., n\}$.
S_{ij}	The cost savings from implementing the i-th to j-th resilience strategy $\forall i = \{1, 2, ..., m\}$, $\forall j = \{i + 1, ..., m\}$.
t_{ij}	The time savings from implementing the i-th to j-th resilience strategy $\forall i = \{1, 2, ..., m\}$, $\forall j = \{i + 1, ..., m\}$.
C_j	The expected implementation cost of the resilience j-th strategy resilience strategy, $\forall j = \{1, 2, ..., n\}$.
t_j	The expected implementation time of the resilience j-th strategy resilience strategy, $\forall j = \{1, 2, ..., n\}$.
L_i	The lower limit of sustainability goal for the i-th service design challenge that must be achieved, $\forall i = \{1, 2, ..., m\}$.
B	The available budget for implementing the resilience strategies.
T	The time bound for implementing the resilience strategies.
n	Number of resilience strategies (design requirements).
m	Number of service design challenges (customer requirements).

and endanger the sustainability of the system. The implemented resilience strategies should be non-dominant subject to cost and time constraints. We formulated a multiple objectives mathematical model to address the challenges in service design. Our QFD-based, multi-objective binary integer programming model is formulated as follows:

$$
\begin{aligned}
& Max f_1(X_1) = \sum_{j \in X_1} RES_j x_j \\
& Max f_2(X_2) = \sum_{j \in X_2} RES_j x_j \\
& \ldots \\
& Max f_p(X_p) = \sum_{j \in X_p} RES_j x_j \\
& S.t. \\
& \sum_{j=1}^{n} C_j x_j - \sum_{j=1}^{n} \sum_{i>j}^{m} S_{ij} x_i x_j \leq B \\
& \max_{j=1}^{n} \{t_j x_j\} - \max_{j=1}^{n} \left\{ \left(\sum_{i=1}^{m} t_{ij} x_i\right) x_j \right\} \leq T \\
& \sum_{j=1}^{n} R_{ij} x_i \geq L_i \quad \forall i = \{1, 2, ..., m\} \\
& x_j \in \{0, 1\} \qquad \forall j = \{1, 2, ..., n\}
\end{aligned}
\tag{3}
$$

x_j is the binary decision variable equals 1 if the resilience strategy j is selected, and equals 0 otherwise. X_k is the k-th category (i.e. a subset) of resilience strategies, $k \in \{1, ..., p\}$, i.e. $X_k \subset \{1, ..., n\}$ and $X_k \cup ... \cup X_p = \varnothing$; p is the number of categories of resilience strategies defined according to the resilience attributes, i.e. the number of different resilience attributes; $f_k(X_k)$ is the objective function corresponding to the resilience-strategy category $k \in \{1, ..., p\}$. Note that we extend the approach of Park and Kim (1998) and other general applications of QFD by including time savings from parallel implementation of correlated strategies, time constraints, and policy-related constraints imposed by sustainability objectives within our model of optimization. We argue that the response and recovery time are important factors in developing resilience capability.

Considering p resilience attributes, we formulate p different and conflicting objectives among the resilient strategies. Hence, the portfolio of satisfactory efficient solutions in Eq. (3) needs to be established through relationships with the decision-makers. For the first time, we used the Brute Force search to find all optimal resilience strategies for a sustainable service design. One of the most important advantages of this particular method is that it enables all of the strategies to be discovered quickly. In comparison with other methods used in the literature, the Brute Force algorithm, involves a complete short search and has less error. It can also check the feasibility of all of the strategies, calculate their objective functions simultaneously, and find the best combinations. Another advantage of this algorithm is that it is also used to optimize the single and multiple-objective mathematical models. For example, Liu et al. (2016) benefited from this efficient approach to find the optimal solutions through their multiple-objective scheduling model, demonstrating that when the size of the problem is small, the Brute Force algorithm performs better and faster than other algorithms such as the Genetic algorithm. So, we use the Brute Force algorithm to find the Pareto Optimal Solutions (POSs), which are predominant in other feasible solutions. All the POSs have the same value, and the decision-makers (i.e., the QFD team in our case) can choose those that they prefer.

Application in m-Health Service Design of Bangladesh

In this section, we use the proposed model for designing resilient and sustainable services in the m-health (i.e., mobile health) services of Bangladesh. M-health has made remarkable contributions to the sustainable and millennium development goals in developing countries where health services are a major issue. It is proposed that m-health has the potential to address the healthcare service problems arising from a shortage of doctors, inadequate health infrastructure, high cost of access to health service, limited financial resources and inequitable access to health services (USAID, T.r., 2012).

To implement the DSF in m-health settings within Bangladesh, a QFD workgroup was formed, consisting of an academic, three doctors, and two healthcare officers. The study was conducted on one of the districts of Chittagong—the port city and commercial capital of Bangladesh. The selected district is rural and has widely adopted m-health service. We carefully selected the QFD working group members to ensure that the members are highly knowledgeable and experienced about the context. We considered the experience of doctors (more than three years of experience in m-health service) and their availability for participation in the workshop and top-level admin staff who are responsible for managing m-health service in the district as key criteria for including QFD work group members. An academic who was involved in m-health service research is included as an external stakeholder and a representative of the demand side of the service.

Over a period of two months, we conducted interviews and workshops with the QFD group members to address various issues. This research was conducted in several steps. At the first step, corresponding to m-health service design challenges and mitigation strategies we used semi-structured interview protocol to collect data from QFD work group members. The list of challenges and mitigation strategies explored from the interviews were quite consistent among the interviewees. Therefore, we did not collect further data from other interviewees apart from the six members of the QFD working group. Appendix C presents the semi-structured interview protocol. To assign importance weight of challenges using AHP and determine the relationship between challenges and strategies, we used a questionnaire to collect information from the QFD group members in workshop 1. Appendix D presents the questionnaire related to AHP and QFD. In the second stage to determine the relationship between sustainability goals and strategies we used a questionnaire to collect data from the QFD members during workshop 2. Appendix E presents the questionnaire related to the relationship between sustainability goals and strategies. In the third stage, to collect data regarding optimization, we organized workshop 3. During this workshop, we collected data regarding cost and time of implementation of each strategy. The data related to the interrelationship of strategies and resultant cost and time saving were collected using a semi-structured questionnaire. Appendix F presents the questionnaire related to the interrelationship of strategies. The outcomes of the QFD application are detailed in the following section.

Results

Phase 1 results

In the first phase, the QFD team discussed the m-health service design and delivery challenges, and several of these challenges were explored in depth. The team frequently mentioned "lack of awareness", "lack of understanding of customer requirements", "poor logistical support", and "service standard". Table 3 lists the challenges revealed by the field study, which are also supported by the existing literature. For ease of analysis, the QFD team were asked to categorize the list of challenges. Three major groups of challenges were generated; they related to people, process, and organization. In this regard, we checked the agreement of the QFD working group members on the classification process and their agreement was unanimous.

After the list of challenges and their grouping were finalized, the QFD team was asked to assign a score to each group (people, process and organization) based on its perceived importance, using the AHP (Vaidya & Kumar, 2006). AHP is a well-established decision-making approach that is multi-criteria. Moreover, AHP has proven to be a robust tool for addressing challenges and making decisions in intricate environments (Wang et al., 1998). In addition, AHP is easier, less stringent and less time-consuming than other decision-making techniques such as data envelopment analysis and analytical network process (Darko et al., 2019). Team members' responses were averaged to establish the weights, while participants were tasked with evaluating the significance of each challenge within the sub-groups through the use of AHP. The

Table 3 Explored service design challenges along with their synthesized weights

Group	Service design challenges	Weight W_i
People	Inadequate knowledge of customer requirements	0.099
	Lack of responsiveness from people in service-delivery process	0.083
	Problem of employee perception and attitude	0.045
	Lack of awareness among the customers	0.089
Process	Logistical problem (technology, infrastructure, facilities, information systems)	0.111
	Technical failure	0.040
	Unpredictability of demand	0.083
	The problem late service delivery)	0.081
	System's security	0.044
Organization	Lack of control mechanism	0.100
	Lack of incentives	0.078
	Lack of service standards and performance measurement system	0.084
	Lack of training, learning and development	0.064

synthesized weights of the challenges, i.e., W_i, $i \in \{1, \ldots, m\}$ were obtained; these are shown in Table 3. The overall inconsistency ratio for the AHP weight calculation was 0.06.

The less important challenges (weight < 0.05) were disregarded and the remainder were retained for further analysis. In stage 1, after determining challenges and their weights, the QFD team were also asked to determine the resilience strategies corresponding to the challenges and disruptions. For ease of analysis, the QFD team were asked to categorize the list of resilience strategies under three attributes: readiness, response and recovery. In our study, readiness is conceptualized as the main capability (pre-disruption) required to decrease effects of disruptions. Response mechanisms help a system to react in a timely manner to recover from a crisis by reconfiguring the processes and resources of an organization (Chowdhury & Quaddus, 2016). Notably, in this study, the strategies with the resilience attributes of readiness, response and recovery are applied to m-health service systems, although all these resilience attributes are the same for all resilience systems, according to the literature. The results revealed that some of the strategies explored in the literature are highly relevant to service operations (e.g., St1- Service demand planning and forecasting, St5- Service innovation by technology development) as well as several generic items which could also be applicable to production environments (e.g., St2- Offering training to employees, St3- Contingency planning and keeping back up for uncertainties). The strategies identified in accordance with these attributes are presented in Table 4.

In the next step, we established the connection between the challenges in service design (WHATs) and the strategies for resilience intended to address them (HOWs), referred to as the WHAT-HOW relationship (i.e., R_{ij}'s). The R_{ij} values obtained from the seven respondents were averaged; these average scores are given in Table 5. Then the AI_j and RI_j values were calculated for different resilience strategies using Eq. (1) and (2), respectively.

Table 5 shows that resilience strategies: St8 (hiring skilled human resources), St1 (demand planning and forecasting), St5 (service innovation by technology development) and St11 (adequate supervision and follow up of service delivery process) have the highest AI_j and RI_j values. In other words, the most important strategies are: demand planning and forecasting, hiring skilled human resources, service innovation by technology development, as well as adequate supervision and the follow-up of service delivery processes.

Phase 2 results

In phase 2, the QFD team identified the sustainability objectives for the m-health service within the health department of Bangladesh. These objectives are outlined in Table 6. The initial sustainability objective is to minimize expenses linked to health service delivery (the economic aspect, i.e., profit) which can be quantified by comparing the m-health service delivery cost with the cost of service delivery in a physical setting, such as medical centers in various locations. The second sustainability goal is to increase patients' satisfaction (the social aspect, i.e., people) which can be deduced from the feedback of patients who have used the service. The third goal is to increase the accessibility of healthcare services (the social aspect, i.e., people). The fourth goal is to reduce the environmental impact (i.e., planet) which is indicated by a reduction of energy consumption, paperwork, other documentation, and

Table 4 Strategies to mitigate the challenges with resilience attributes

Attributes	Strategies
Readiness	St1- Service demand planning and forecasting
	St2- Imparting training to employees
	St3- Contingency planning and keeping back up for uncertainties
	St4- Improving awareness of the customers by extensive campaigns
	St5- Service innovation by technology development
Response	St6- Supply adequate logistical support
	St7- Service network integration
	St8- Hiring skilled human resources
	St9- Ensuring proper incentives and recognition for performance of the employees
	St10- Managing performance quality
Recovery	St11- Governance of service delivery process
	St12- Gathering customer feedback and incorporating voice of patients/customers in service process
	St13- Offer better service to recover the service delivery failure

Table 5 Relationship between challenges in service design and the strategies used to address them

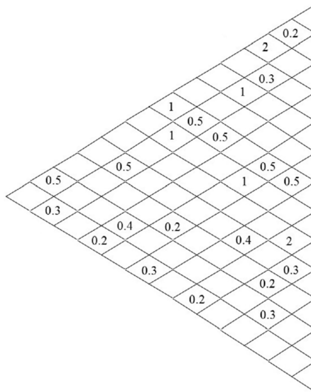
R_{ij}		Strategies												
Challenges	W_j	St1	St2	St3	St4	St5	St6	St7	St8	St9	St10	St11	St12	St13
Understanding customer needs	0.099	3.57	1.85	0	0	2.14	0	0	9	1.57	0	0	0	0
Lack of responsiveness	0.083	3.28	3.85	0	0	0	0	6.43	4.71	3.57	3	4.71	7.29	3.57
Lack of awareness	0.089	0	0	0	9	3.57	0	0	0	0	0	0	0	0
Logistical disruption	0.111	2.71	0	7.29	0	2.71	9	2.14	0	0	0	0	0	0
Volatility in demand	0.083	9	0	3.85	0	0	2.71	2.14	2.43	0	0	0	0	0
On time service delivery	0.081	7.29	2.43	3.57	0	6.43	6.43	3	6.43	3.57	3.85	4.71	5.57	3.57
Lack of control mechanism	0.100	0	0	0	0	4.71	2.14	0	3.57	0	6.43	9	0	0
Incentives to employees	0.078	0	0	0	0	0	0	0	0	9	0	0	0	0
Service standard measurement	0.084	0	0	0	0	3.85	0	0	1.85	0	3.85	4.71	4.71	0
Lack of training	0.064	0	9	0	0	0	0	0	0	0	0	0	0	0
AI_i		2.26	1.28	1.42	0.80	2.14	1.96	1.19	2.52	1.44	1.52	2.07	1.8	0.59
RI_j		0.11	0.06	0.07	0.04	0.10	0.09	0.06	0.12	0.07	0.07	0.10	0.09	0.03

Table 6 Sustainability goals

Goal 1 (Sus1)- Reduce the cost of health services
Goal 2 (Sus1)- Ensure patients' satisfaction
Goal 3 (Sus1)- Provide accessibility to healthcare service to increase in the number of served patients
Goal 4 (Sus1)- Reduce environmental impact

medical waste when compared with running a physical setting. Following the identification of sustainability goals, an evaluation was conducted to examine the association between resilience strategies and these goals, aiming to understand the contribution of each resilience strategy to achieving sustainability objectives. Figure 4 shows the relationship between resilience strategies and sustainability goals. The row and column elements in Fig. 4 are the strategies and the sustainability goals from Tables 3 and 6, respectively.

Fig. 4 Resilient-sustainable service design model



Strategies	Weight	Sus1	Sus2	Sus3	Sus4	AI_j	RES_j	Cost	Time
Demand planning	0.11	0.4235	0.3927	0.2354	0	1.0516	0.0869	1	2
Training	0.06	0.2142	0.2826	0.111	0.3342	0.942	0.0779	5	4
Contingency planning	0.07	0	0.2695	0	0	0.2695	0.0223	2	1
Improving awareness	0.04	0.154	0	0.36	0.1884	0.7024	0.0581	2	3
Service innovation by technology development	0.1	0.471	0.729	0.557	0.557	2.314	0.1913	11	5
Improving logistical support	0.09	0	0.4239	0.5787	0	1.0026	0.0829	9	1
Service network integration	0.06	0	0.54	0.231	0	0.771	0.0637	5	2
Hiring skilled HR	0.12	0.3288	0.7716	0.4284	0.3288	1.8576	0.1536	9	5
Incentives and recognition	0.07	0	0.0798	0.1498	0	0.2296	0.019	5	3
Setting performance standard	0.07	0	0.5103	0.1918	0	0.7021	0.058	3	4
Governance of service process	0.1	0	0.557	0.214	0	0.771	0.0637	5	1
Customer feedback and include voice of customer	0.09	0	0.7326	0.4239	0	1.1565	0.0956	3	3
Better service to recover service failure	0.03	0	0.2187	0.1071	0	0.3258	0.0269	4	4

In terms of their relative importance, Fig. 4 reveals that AI_5 (for St5, i.e., service innovation through technology development) makes the highest contribution to the sustainability goals, followed by AI_8 (St8, hiring skilled human resource), AI_{12} (St12, customer feedback and include the voice of customers), and AI_1 (St1, demand planning). Figure 4 also shows the cost of implementing the strategies (the last column from the right side of the figure) and the savings obtained by introducing two strategies simultaneously (roof matrix as shown at the left side of the figure).

Phase 3 results

In this step, we develop the multi-objective mathematical programming model (as the formulation (3)). We collaborated with the QFD team and arrived at three maximization objective functions corresponding to the resilience strategies by associating them with the three resilience attributes. The multi-objective functions are:

- $f_1(X_1) =$ The total resilience-sustainability score from the ‘readiness’-related strategies, including St1, St2, St3, St4, and St5;
- $f_2(X_2) =$ The total resilience-sustainability score from the ‘response’-related strategies, including St6, St7, St8, St9, and St10;
- $f_3(X_3) =$ The total resilience-sustainability score from the ‘recovery’-related strategies, including St11, St12, and St13.

The available budget B is set at 20 million BDT (Bangladeshi taka). Those for Sus2 (customer satisfaction), Sus3 (accessibility to healthcare service), and Sus4 (reducing the environmental impact) are 25%, 25%, and 10%, respectively. The time frame established for the implementation of strategies, i.e., T, is 5 years. The multi-objective mathematical programming model is formulated as:

$$Max\, f_1(X_1) = \sum_{j=1}^{5} RES_j x_j \tag{4}$$

$$Max\, f_2(X_2) = \sum_{j=6}^{10} RES_j x_j \tag{5}$$

$$Max\, f_3(X_3) = \sum_{j=11}^{13} RES_j x_j \tag{6}$$

$$S.t. \quad \sum_{j=1}^{13} C_j x_j - \sum_{j=1}^{13} \sum_{i>j}^{13} S_{ij} x_i x_j \leq 20 \tag{7}$$

$$\max_{j=1}^{13} \{t_j x_j\} - \max_{j=1}^{13} \left\{ \left(\sum_{i=1}^{13} t_{ij} x_i\right) x_j \right\} \leq 5 \tag{8}$$

$$\sum_{j=1}^{13} R_{1j} x_1 \geq 0.10 \tag{9}$$

$$\sum_{j=1}^{13} R_{2j} x_2 \geq 0.25 \tag{10}$$

$$\sum_{j=1}^{13} R_{3j} x_3 \geq 0.25 \tag{11}$$

$$\sum_{j=1}^{13} R_{4j} x_4 \geq 0.10 \tag{12}$$

$$x_j \in \{0, 1\} \quad \forall j = \{1, 2, ..., 13\} \tag{13}$$

Where, $x_1, x_2, ..., x_n \geq 0$ and $x \in \{0, 1\}$, $RI_j =$ relative importance scores of the strategies and $S_1, ..., S_n$ and $n = 1, ..., 13$; $C_1 x_1, C_2 x_2, ..., C_{13} x_{13}$ are the costs of implementing the resilience strategies 1, 2,..., 13. $S_{1,3} x_1 x_3$ are the savings achieved through the concurrent execution of the strategy 1 and 3 (others are similar savings functions). Values of RI_j, S_{ij}, and C_{ij} are obtained from Fig. 4. It is also noted that C_{ij} and S_{ij} are obtained from the QFD team via interviews.

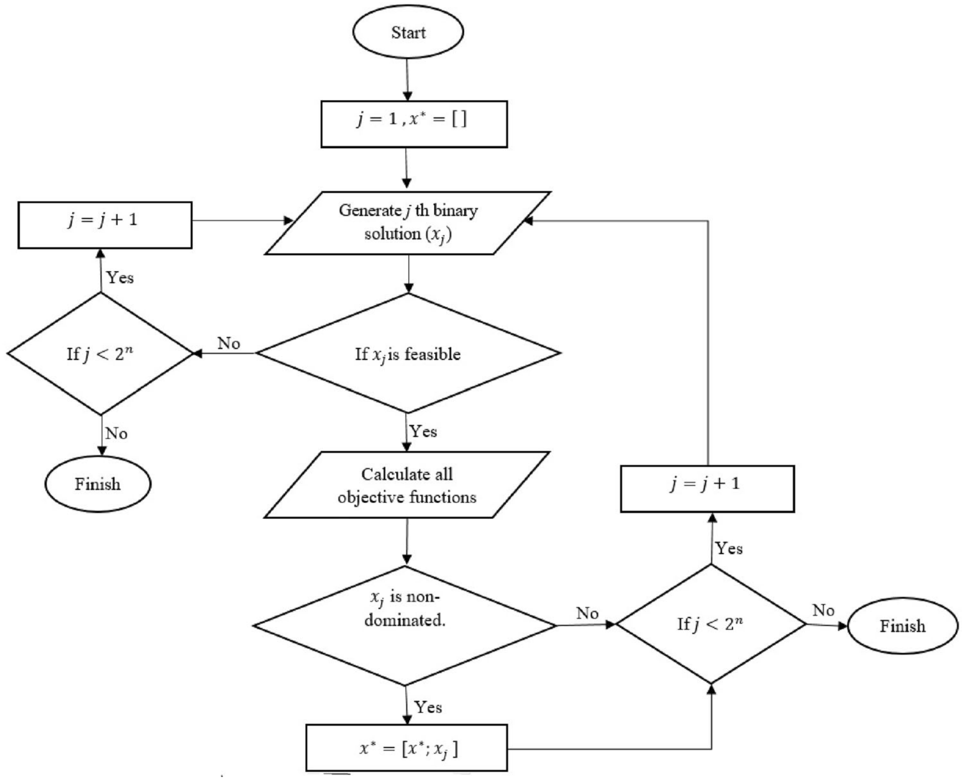


Fig. 5 The flowchart of the Brute Force algorithm

Table 7 Pareto optimal solutions of the proposed QFD model

POS number	Objective		x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}
1	f_1	0.2452	1	1	1	1	0								
	f_2	0.2116						0	0	1	0	1			
	f_3	0.0956											0	1	0
2	f_1	0.2452	1	1	1	1	0								
	f_2	0.1217						0	1	0	0	1			
	f_3	0.1593											1	1	0

As stated earlier, in this study, the Brute Force algorithm is used to create the proposed multi-objective model. Since all the decision variables are binary, there are 2^n feasible and infeasible solutions (Fasoli & Panzeri, 2019). This algorithm, which is a fast-ordering method for the binary decision was introduced by Robert and Malandain (1998). They generated all the potential variables for seven binary variables after finding a small initial function which was efficient. The flowchart depicted in Fig. 5 illustrates the steps of the developed Brute Force algorithm for our proposed QFD multiple-objective model. It is clear from the flowchart that after generating all 2^n solutions, the constraints are checked and the infeasible ones are removed. Then, among the feasible solutions, the non-dominated ones (POSs) are found. It is worth mentioning that all the POSs have the same value and none of them dominates any of the others. Moreover, because the algorithm is able to find all optimal answers, it provides a wide range of choices to the QFD team who can select the ones they prefer.

In the proposed model ($n = 13, B = 20$), there are 2^{13} solutions of which only 34 are feasible, and two of these feasible solutions are POSs. Table 7 gives the details of these two solutions. The powerful software of MATLAB was used to code the algorithm and the computer used had 7500 U CPU, 12GB RAMDDR4, Intel core i7, and the running time was only 3.15 s.

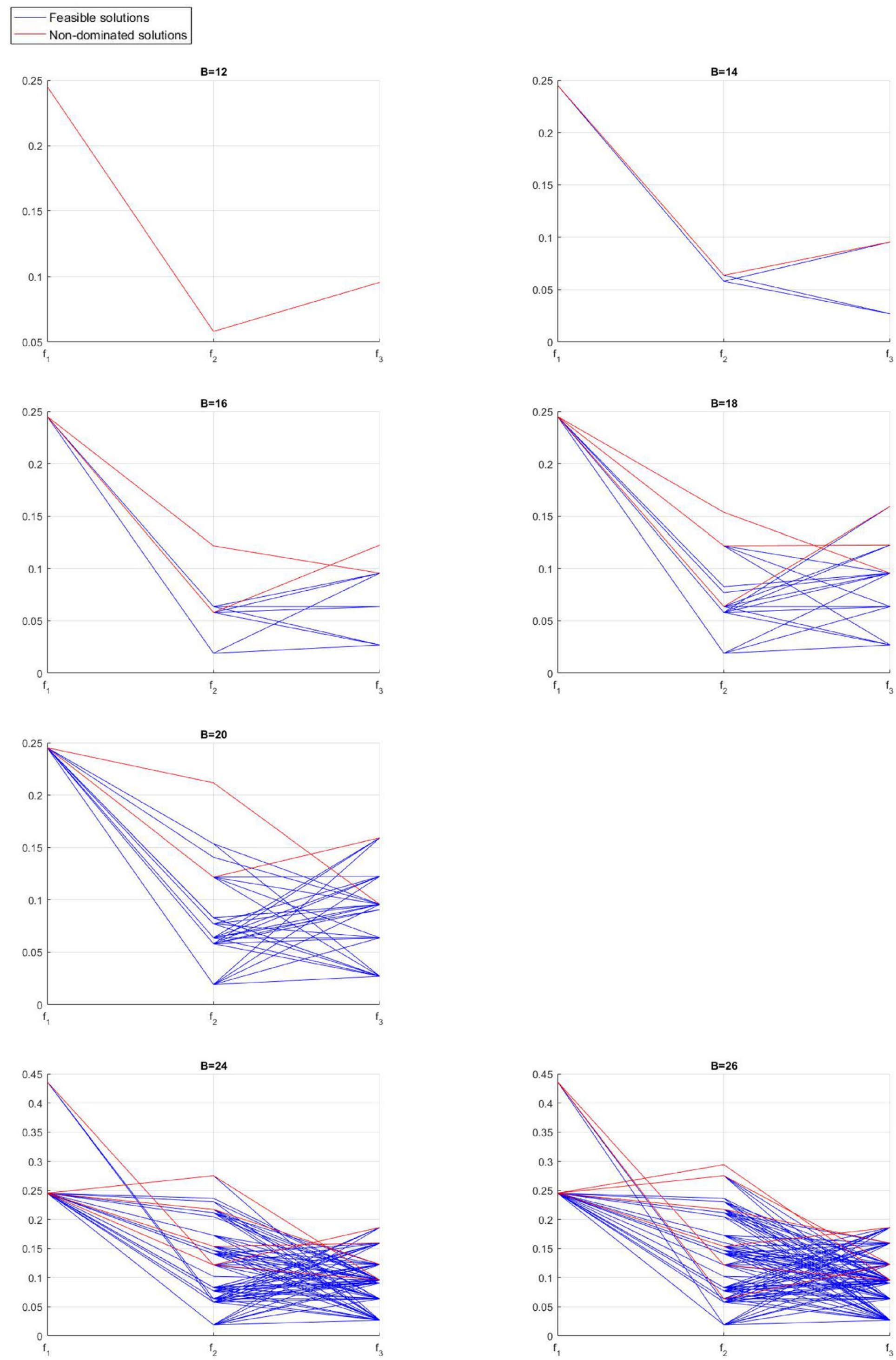
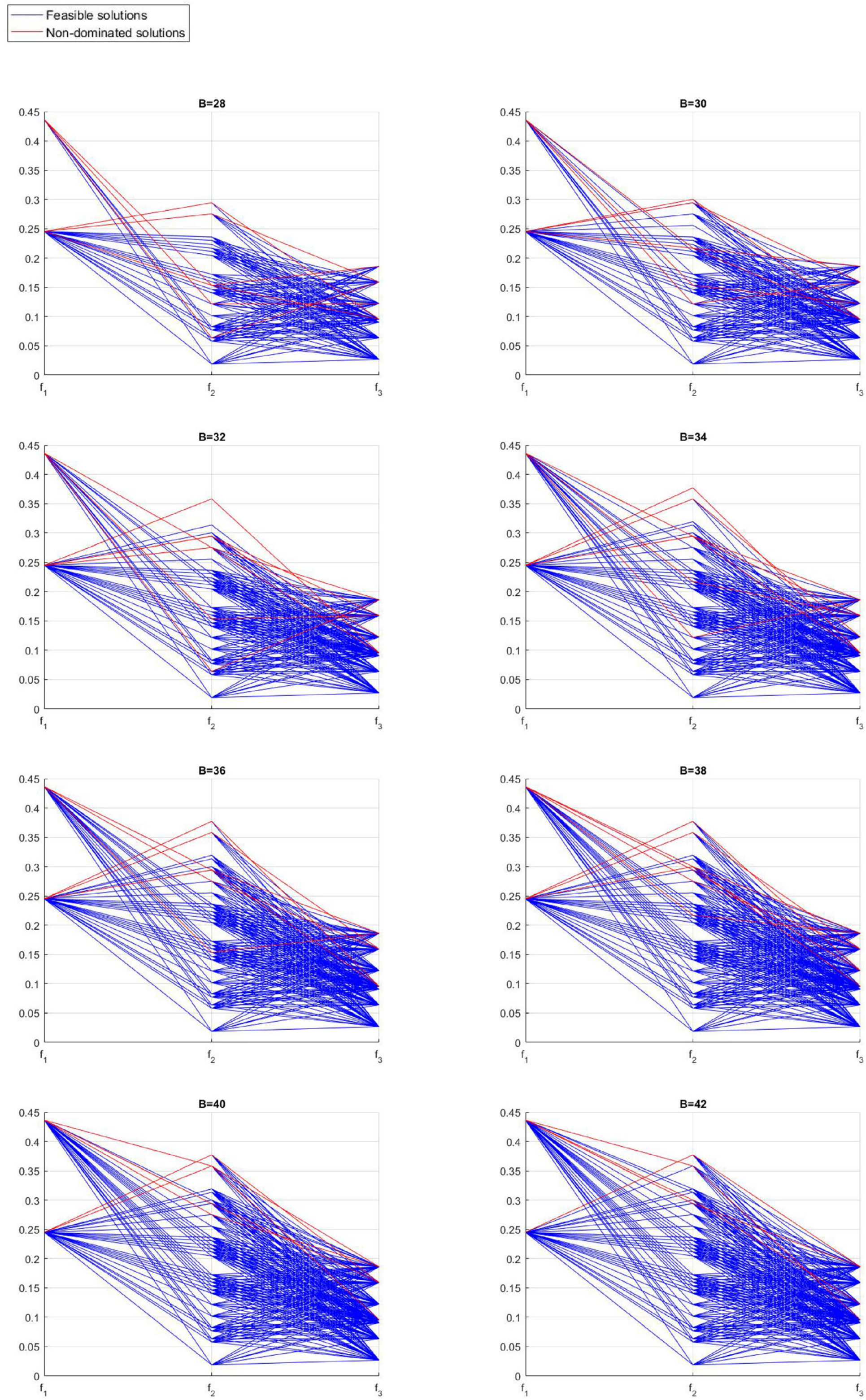


Fig. 6 Sensitivity analysis of available budget (B)

It is clear that in both POSs, the first four variables of the 'readiness'-related strategies (x_1 to x_4) are selected due to the last four constraints (Eq. (9) to Eq. (12)) as they are directly related to the sustainability goal. In this regard, these four variables equal one in all of the 34 feasible solutions. However, some variables (e.g., x_5 and x_{13}) are not selected for either POS because they are either costlier or more time-consuming than the other variables according to the budget ceiling. In other words, if the most important parameter (B) increases, these non-selected variables might be chosen. Appendix G shows how the POSs dominate all the 34 feasible solutions. We reiterate that the implementation of these strategies requires both tangible and intangible resources from the government of Bangladesh.

Fig. 6 continued



Various stakeholders at the district and sub-district levels must be involved in this implementation plan. Finally, as per our resilient-sustainable service concept (Fig. 1), feedback regarding HOWs and WHATs must occur to ensure the continuing improvement of service delivery.

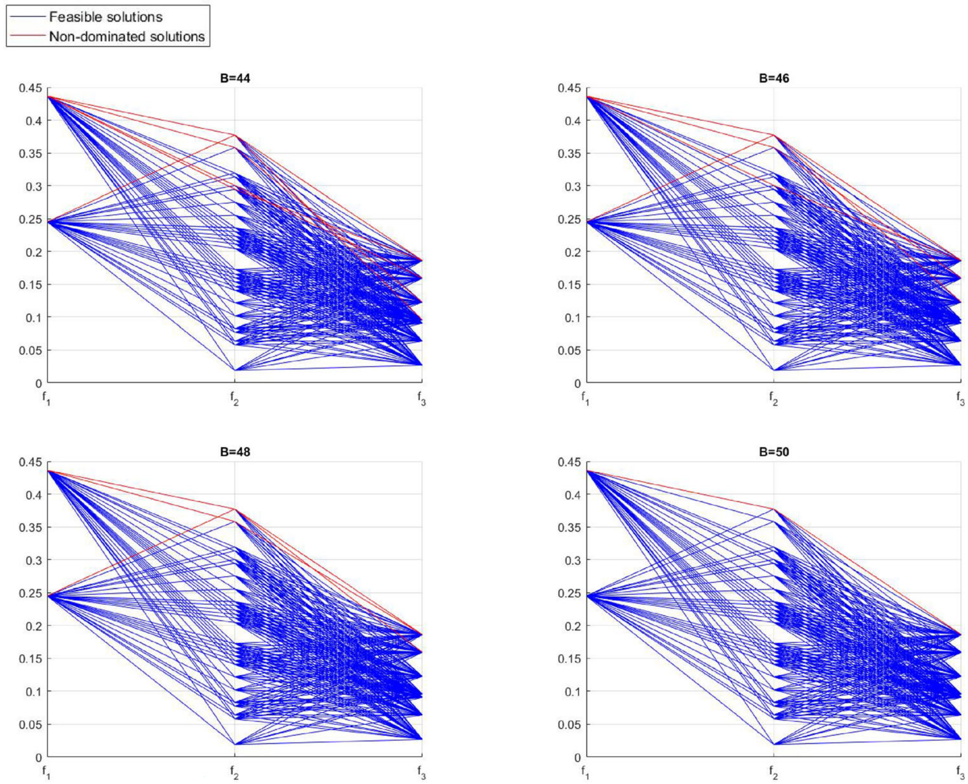


Fig. 6 continued

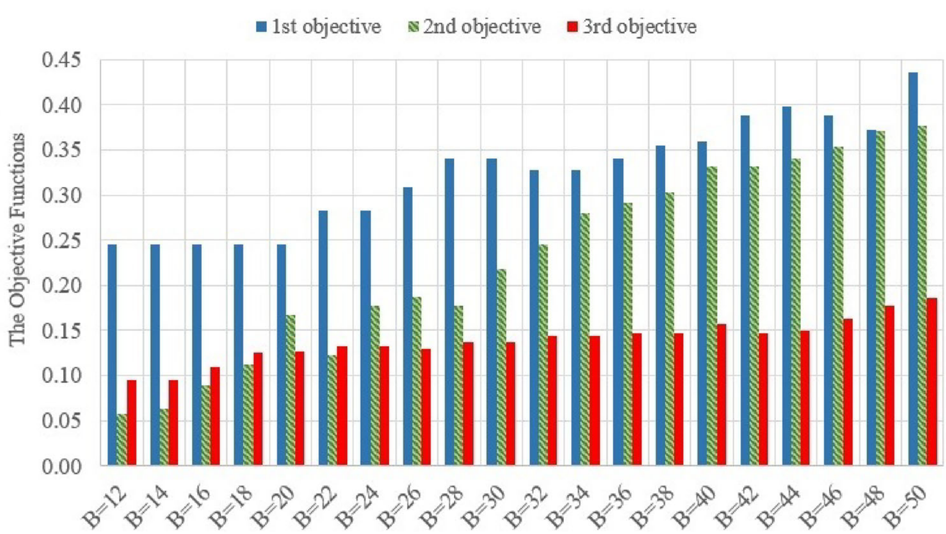


Fig. 7 Impact of *B* parameter of the objective functions

Sensitivity Analysis

Understanding the pivotal role of budget allocation (*B*) in decision-making processes is imperative for managers. A larger budget inherently offers decision-makers and QFD teams a broader array of choices, potentially leading to more effective solutions. Therefore, managers should carefully consider allocating sufficient resources to decision-making processes to ensure a diverse and robust set of options. So, the relationship between budget allocation (*B*) and decision-making processes is pivotal, as it directly impacts the breadth of available choices. Thus, it's imperative to ascertain how variations in this critical parameter (*B*) influence both the quantity and quality of POSs.

Establishing clear boundaries for *B* is essential for effective decision-making. The analysis results indicate that solutions become infeasible below a *B* value of 12 million BDT, indicating the minimum threshold required for viable outcomes. Conversely, solutions remain unchanged beyond a B value of 50 million BDT, suggesting diminishing returns beyond this point. Thus, managers should delineate B within the interval $[12, 50]$ to optimize resource allocation.

The effects of different B values on objectives are depicted in Fig. 6, which comprises 20 sub-figures featuring parallel coordinates. For a comprehensive exploration of B effects across the range of 12 to 50 million BDT, refer to Appendix H. As Fig. 6 shows, an increase in B correlates with an enhancement of the quality of optimal solutions, evidenced by the improvement in red lines. Moreover, higher B values are associated with a greater number of feasible solutions, as illustrated by the proliferation of blue lines. This underscores the importance of allocating adequate resources so as to maximize the effectiveness of solutions.

Figure 6 reveals a notable trend: as B increases, the quality of optimal solutions (depicted by the red lines) improves. For instance, the initial sub-figure representing the lower bound of B ($B = 12$ million BDT) shows a solitary feasible solution, which coincides with the optimal one. Conversely, the final sub-figure ($B = 50$ million BDT) has the highest number of feasible solutions.

To examine more closely the impact of B on the feasibility of solutions in finer detail, see Appendix I. Here, it becomes evident that for B values below 12 (e.g., $B = 10$ million BDT), no feasible solutions emerge. Conversely, when B is over 50 (e.g., $B = 52$ million BDT) here are no divergent objectives compared to $B = 50$ million BDT. This observation is depicted in Fig. 7, where the augmentation of the budget invariably corresponds with an increase in all three objective functions. This bar chart illustrates how much each of these objective functions changes independently as the available budget increases. The first objective function, which is the total resilience-sustainability score from the 'readiness'-related strategies, generally increases with the increase of the budget. However, it should be noted that in some intervals of B, this objective function either remains constant or even decreases. For example, when B is between 12 and 20 million BDT, the optimal value of the first objective function is fixed equal to 0.245. But this amount increases slightly with the increase of the budget between 22 and 24 million BDT. This objective function, after a fluctuation value in the range of 30 to 48 million BDT, peaks at 0.436 when the budget is 50.

The second objective, as the total resilience-sustainability score from the 'response'-related strategies, is more sensitive than other objective functions in such a way that it increases significantly with the increase of the budget. Except in two cases where B equals 22 and 28 million BDT, which had a very small decrease compared to the budget of 20 and 26 million BDT, respectively. In the remaining cases, the value of this objective function increases with the increase of the budget. In general, when the budget is 12 million BDT, this objective function is equal to 0.058, and when the budget is 50 million BDT, the amount of this objective function increases by 5.5 times. The third objective which equals the total resilience-sustainability score from the 'recovery'-related strategies, has a slight increase with increasing budget. The increase of this objective function is so insignificant that when B is between 18 and 44 million BDT, the value of this objective function remains almost unchanged. But overall, its trend indicates a 1.94 times increase from the beginning to the end.

Budget allocation should be dynamic and responsive to changing circumstances. Managers should continuously monitor the relationship between budget and outcomes, adjusting allocations as needed in alignment with evolving goals and market conditions. This adaptive approach ensures that resources are effectively utilized to support strategic objectives and drive organizational success. Indeed, by understanding the nuanced relationship between budget allocation and decision-making outcomes, managers can maximize value within budget constraints. This involves not only considering the quality of solutions, but also the efficiency of resource utilization.

Discussions

The aim of this study was to develop a decision support framework for a resilient-sustainable service design for the m-health service system in Bangladesh. To this end, we identified the service design challenges and mitigation strategies. We employed an interactive methodology, comprising three phases, utilizing a QFD-based optimization approach, to identify an effective portfolio of flexible strategies.

We identified fourteen challenges (see Table 3) in the m-health service design (WHATs in QFD terms) in Bangladesh which are classified into three major groups: people, process, and organization-related challenges. Although these challenges are contextual, extant literature validates our findings. In determining the importance of the challenges using AHP, it was found that the most important challenges related to the people factor are: lack of knowledge about clients' requirements, lack of awareness of the service, and the poor responsiveness from employees.

Furthermore, we found that the most important challenges related to designing the service are logistical disruptions, unpredictable demand, and on-time delivery of service. The QFD team reported that m-health service centers do not have adequate logistical support in terms of mobile phones, network coverage, information systems, and utilities. These are common problems in resource-poor economies and contribute to the failure to deliver effective and efficient service.

Our results indicate that the most significant challenges facing service organizations are: lack of supervision and/or service standards, and poor incentives for employees. As mentioned earlier, the lack of funding in resource-poor economies hampers the development of adequate systems for the supervision and monitoring of service facilities; in turn, this affects the standard of service quality. Further, the lack of incentives discourages the effective and efficient delivery of service as, without adequate incentives, service providers lack enthusiasm.

The results also indicated strategies (HOWs) that could help to mitigate the challenges. It was found that the most important readiness, response, and recovery strategies are: demand planning and forecasting, hiring skilled human resources, and adequate governance of the service delivery process. Conversely, tardy delivery of service, lack of understanding of customer requirements, and poor logistical support impede the delivery of quality service. Hence, several flexible strategies such as demand planning and forecasting, service innovation, and increasing skilled human resources to meet service demand on time play significant roles in mitigating the challenges by facilitating resource planning (e.g., human resource, logistical resource requirements, etc.).

Finally, we developed a 0-1 multiple-objective-based framework to find the most efficient resilient-sustainable strategies for implementation by interacting with the QFD team to determine the goal constraints imposed by budget, time, and sustainability considerations. We used the Brute Force algorithm to optimize this model. Using the aforementioned method, all the non-dominated optimal solutions were found very quickly (approximately three seconds). In our proposed framework, demand planning, training, improving awareness, technology-enabled service innovation, logistical support, service network integration, hiring skilled HR, collection of feedback to incorporate the voice of customers, and better recovery service were selected for a portfolio of efficient and optimal strategies to be implemented to achieve the sustainability goals.

Because the budget is the most important parameter in the proposed model, after finding the lower and upper bounds of this parameter ($[12, 50]$), we inferred that the objectives that were allocated a greater budget could provide more feasible solutions; thus, the Pareto front has better quality.

It can be inferred that the decision model facilitates the development of a long-term, resilient, and sustainable service system. Notably, the flexibility of our decision support model allows it to adapt readily to diverse scenarios, extending its applicability in various contexts. Our decision model makes a distinctive contribution to the m-health service literature. While existing studies in the m-health service domain address various issues and objectives, they often lack a comprehensive decision model specifically tailored for the development of a resilient and sustainable service design.

For instance, the study by Tushar et al. (2023) highlights the importance of integrating sustainability in healthcare services. Our findings align with this by demonstrating that integrating flexible strategies such as demand planning and forecasting, and improving logistical support can significantly improve the sustainability of m-health services in Bangladesh.

Similarly, the study by Rahman et al. (2022) on key performance indicators for a sustainable recovery strategy in healthcare SCs during the COVID-19 pandemic, emphasizes the need for a resilient response to disruptions. Our research extends this by not only identifying key performance indicators, but also providing a robust decision support model that can help m-health service providers select optimal strategies to ensure service continuity and sustainability during disruptions.

In summary, the first goal of the current study is to extend a decision model by identifying the challenges (WHATs) associated with designing a resilient and sustainable service system, and choosing optimal tactics and strategies (HOWs) to address difficulties is essential for attaining the organizations' resilience and sustainability objectives. In line with the research objective, we applied a multi-objective optimization model integrated with a multi-phased QFD approach, which is a widely-accepted tool for prioritizing and designing strategies by examining the effectiveness of strategies used to mitigate challenges/risks/disruptions. Therefore, in our study, we used QFD to identify the flexible strategies that are effective in mitigating existing service design challenges and meeting the sustainability goals. As well as QFD, we used multi-objective optimization to determine the most efficient strategies for achieving particular goals (Chowdhury & Quaddus, 2015).

Hence, this work makes two noteworthy contributions. First, by integrating resilience terms ('readiness, response, and recovery') with sustainability, we propose the 'resilient-sustainable service concept' to develop the traditional 'service concept' and use the 'evolutionary, ambidextrous, and multifaceted process' view and service-dominant logic. Second, our research demonstrates the practical application of the proposed resilient-sustainable service concept through a multi-phase optimization approach based on QFD (discussed in the methodology section), which can be fine-tuned and applied to resolve a range of similar issues.

The DSF developed in our study can be adapted for use in analogous problem domains and diverse settings associated with service design. It has the flexibility to be contextualized and applied in various problem areas. While the findings of this research are applicable to a certain degree, they are generalizable as we utilized the context of a specific district in the design of a resilient and sustainable m-health care service.

Theoretical Implications

The current paper introduces the 'resilient-sustainable service concept' (see Fig. 1), which extends the service concept proposed by Goldstein et al. (2002) and the sustainable service concept of Chowdhury and Quaddus (2016). This study develops a DSF and applies it in m-health service settings to demonstrate the practical application of the resilient-sustainable service concept. The theoretical contributions of this study are fourfold:

- Development of a Unique Decision Framework: This research creates a novel decision framework for resilient-sustainable service design, empirically demonstrating that service systems must be resilient to achieve sustainability. This concept is universally applicable across various service industries, promoting global sustainability efforts.
- Extension of QFD Integrated Nonlinear Optimization: Our approach builds on the work of Park and Kim (1998) by integrating both cost and time factors into decision-making processes, demonstrating that simultaneous implementation of strategies can save both cost and time. This has significant global implications for industries aiming to optimize resources efficiently amid global economic challenges.
- Identification of Key Service Design Challenges: By identifying the most significant challenges to service design and the flexible strategies to overcome them, our approach can guide global management in implementing feasible and optimal strategies. This methodology benefits international organizations striving to strengthen service resilience in diverse regional contexts.
- Introduction of Interactive Decision Models: This study employs an interactive decision model to derive a satisfactory portfolio of resilient-sustainable strategies. Unlike traditional QFD-based optimization approaches (Chowdhury & Quaddus, 2016; Delice & Güngör, 2011; Karsak, 2004), our interactive model includes policy constraints and sustainability goals, making it globally relevant for developing resilient-sustainable service models across different sectors and regions.

Managerial Implications

The resilient-sustainable service design decision support model is a valuable tool for m-health service providers seeking to create resilient and sustainable health services. Our DSF assists decision-makers to identify key challenges in service design and implementing resilience strategies to address these challenges, while taking into the account costs, time constraints, and sustainability goals. For decision-makers with significant resource limitations, this framework is essential for selecting strategies that balance the needs of people, planet, and profit. It enables decision-makers to identify and establish an efficient and resilient portfolio of strategies that take into consideration the readiness, response, and recovery capabilities of an organization budgetary and temporal constraints while achieving minimum sustainability goals.

Our DSF model is highly flexible and adaptable to different scenarios, making it applicable in various global contexts. Its versatility allows managers and decision-makers to utilize the model to strategize and meet service demands dynamically, regardless of regional or sectoral specifics. This adaptability is particularly valuable in today's rapidly changing global environment, where service requirements can vary significantly across different regions and industries.

The model's flexibility ensures that it can be customized to address unique challenges and opportunities in diverse contexts, from developed urban areas to remote and underserved regions. It helps decision-makers to tailor their strategies to local conditions, regulatory frameworks, and cultural nuances, thereby improving the relevance and effectiveness of their resilience and sustainability initiatives.

Furthermore, our interactive model facilitates robust decision-maker interaction, enabling the identification and evaluation of optimal solutions that enhance resilience objectives, such as readiness, response, and recovery abilities. This collaborative approach ensures that all stakeholders can contribute their insights and expertise, leading to more comprehensive and well-rounded strategies. By promoting active engagement and dialogue among decision-makers, the model helps build consensus and alignment regarding the best courses of action to achieve sustainability goals.

This approach ensures that strategies are not only globally relevant, but also finely tuned to meet diverse regional needs. It empowers decision-makers to implement solutions that are sensitive to local contexts while maintaining a focus on overarching sustainability principles. As a result, the model supports the development of resilient, sustainable service systems that can withstand and adapt to various disruptions and challenges, ultimately contributing to long-term global sustainability efforts.

In summary, the DSF model's flexibility, adaptability, and interactive nature make it a powerful tool for addressing the complex and varied demands of global service environments. It equips managers and decision-makers with the insights and capabilities needed to navigate the intricacies of resilience and sustainability in a dynamic world, ensuring that their strategies are both effective and contextually appropriate.

Conclusions

In this paper, we introduced a pioneering approach aimed at cultivating resilient and sustainable service design within the m-health sector. Central to our methodology is the development of the "resilient-sustainable service concept", facilitated by an interactive multi-objective optimization-based QFD framework. This conceptual framework is a departure from traditional service paradigms, embracing an evolutionary, ambidextrous, and multifaceted process perspective rooted in service-dominant logic. The application of this novel framework within the context of m-health services in Bangladesh has yielded actionable insights. Through meticulous optimization utilizing the Brute Force algorithm, we identified a robust portfolio of flexible strategies poised to address prevalent service design challenges while concurrently meeting minimum sustainability goals.

Our study addresses the critical need for resilient and sustainable service design in the m-health sector, focusing particularly on challenges prevalent in Bangladesh. Through comprehensive research, we identified key obstacles including a lack of awareness about the service, insufficient understanding of customer requirements, and logistical management inefficiencies. In response, we propose a set of resilient-sustainable strategies, including demand planning, heightened awareness initiatives, technological innovation, streamlined service networks, and efficient service recovery mechanisms.

The contributions of this study extend beyond the mere identification of challenges: we offer a robust decision-support model tailored for m-health service providers. By integrating resilience attributes and sustainability goals, our model serves as a guiding framework for decision-makers. Notably, it helps to recognize and address critical service design challenges while navigating budgetary and time constraints, all while striving to achieve sustainability objectives related to people, planet, and profit.

As the theoretical underpinnings of our research, we introduce the "resilient-sustainable service concept", which advances existing service design and sustainability paradigms. Through empirical application in m-health settings, we demonstrate the practical efficacy of our approach, emphasizing the interconnectedness of resilience and sustainability in service systems. Moreover, our methodology outperforms traditional optimization techniques as it incorporates interactive decision-making processes and policy constraints, resulting in a nuanced portfolio of strategies tailored to specific organizational contexts.

Furthermore, our research underscores the importance of real-world data collection and qualitative analysis, facilitated by close collaboration with stakeholders within the Bangladeshi health department. While our findings provide valuable insights, future research endeavors could focus on strengthening the reliability and validity of data by means of stochastic optimization models and longitudinal studies. Additionally, extending the scope of investigation beyond Bangladesh could shed light on broader system behaviors and inform global best practices in resilient-sustainable service design.

In this study, the DSF we developed demonstrates a robust approach to addressing flexibility challenges within the m-health sector. By leveraging an interactive multi-objective optimization-based QFD framework, our model offers a systematic way to identify and implement resilient and sustainable strategies that can enhance the flexibility of service design processes. By integrating readiness, response, and recovery strategies, such as demand planning, technological innovation, and efficient service network integration, the DSF enables m-health service providers to dynamically adapt to changing requirements and operational constraints. Furthermore, the model's flexibility facilitates the efficient allocation of resources while meeting sustainability objectives, emphasizing the significance of a comprehensive and adaptable decision-making tool in enhancing service design resilience and sustainability. In summary, our study is a pioneering approach to flexible and sustainable service design in the m-health sector. By addressing critical challenges and providing actionable strategies, we contribute to the advancement of both theoretical understanding and practical implementation of service management, with implications extending far beyond our immediate context.

Appendix A

See Table 8.

Appendix B

See Table 9.

Table 8 Cost-saving matrix (million BDT) (S_{ij})

i													
j	1	2	3	4	5	6	7	8	9	10	11	12	13
1		0.2	2	0	0	0	1	0	0	0	0	0.5	0
2			0	0.3	1	0	0.5	1	0	0.5	0	0	0.3
3				0	0	0	0.5	0	0	0	0	0	0
4					0	0	0	0	0	0	0	0.4	0.2
5						0	0.5	1	0	0	0.2	0	0
6							0.5	0	0	0	0	0	0.3
7								0	0	0.4	0	0	0
8									2	0	0	0	0.2
9										0.3	0.2	0	0
10											0	0.3	0
11												0	0
12													0
13													

Table 9 Time-saving matrix (year) (t_{ij})

i													
j	1	2	3	4	5	6	7	8	9	10	11	12	13
1		0.4	0	0	0	0	0	0	0	0	0	0.3	0
2			0	0	1	0	0.2	0	0	0.2	0	0	0.2
3				0	0	0	0.2	0	0	0	0	0	0
4					0	0	0	0	0	0	0	0	0
5						0.4	0.3	0	0	0.4	0	0	0
6							0.1	0	0	0	0	0.3	0.3
7								0.3	0	0	0	0.4	0.2
8									0	0.3	0.5	0	0.5
9										0	0	0	0
10											0.5	0	0.2
11												0	0
12													0
13													

Table 10 Challenges (Ch) of m-Health service design in Bangladesh

No.	Challenge
Ch1	Inadequate knowledge of customer requirements
Ch2	Lack of responsiveness from people in service-delivery process
Ch3	Problem of employee perception and attitude
Ch4	Lack of awareness among the customers
Ch5	Logistical problem
Ch6	Technical failure
Ch7	Unpredictability of demand
Ch8	Late service delivery
Ch9	System's security
Ch10	Lack of control mechanism
Ch11	Lack of incentives
Ch12	Lack of service standards and performance measurement system
Ch13	Lack of training, learning and development

Appendix C

Semi-structured interview protocol:

-In your opinion, what are the challenges of m-Health service design in Bangladesh (for example, inadequate information sharing, cost, etc.)? Please list the challenges below.

1.
2.
.
.
n.

-In your opinion, what are the strategies used to overcome the challenges? Please list the strategies below.

1.
2.
.
.
n.

Dear Respondents:

From the literature review and interview, we identified the following challenges, presented in Table 10, relating to m-Health service design in Bangladesh.

Appendix D

Using the scale: absolute preference (A over B) =9, very strong preference=7, strong preference= 5, weak preference =3, indifference (of A and B) = 1, weak preference (B over A) = 1/3, strong preference = 1/5, very strong preference=1/7, and absolute preference= 1/9, please fill in the yellow highlighted cells of the following pairwise comparison matrix according to the instructions of the workshop coordinator.

See Table 11.

From the literature review and interview, we have identified the following strategies, presented in Table 12,

Table 11 Pairwise comparison matrix of identified challenges

	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8	Ch9	Ch10	Ch11	Ch12	Ch13
Ch1	1												
Ch2		1											
Ch3			1										
Ch4				1									
Ch5					1								
Ch6						1							
Ch7							1						
Ch8								1					
Ch9									1				
Ch10										1			
Ch11											1		
Ch12												1	
Ch13													1

Table 12 Strategies to overcome challenges (St)

No.	Challenge
St1	Service demand planning and forecasting
St2	Imparting training to employees
St3	Contingency planning and keeping back up for uncertainties
St4	Improving awareness of the customers by extensive campaigns
St5	Service innovation by technology development
St6	Supply adequate logistical support
St7	Service network integration
St8	Hiring skilled human resources
St9	Ensuring proper incentives and recognition
St10	Managing performance quality
St11	Governance of service delivery process
St12	Gathering customer feedback and incorporating voice of patients
St13	Offer better service to recover the service

Table 13 The matrix of relationship between challenges and strategies

Strategies (St)	Challenges (Ch)			
	St1. Service demand planning and forecasting	St2. Imparting training to employees	St3. Contingency planning and keeping back up for uncertainties	St13. Offer better service to recover the service
Ch1. Inadequate knowledge of customer requirements	Ch1St1	Ch1St2	Ch1St3	
Ch2. Lack of responsiveness from people in service-delivery process	Ch2St1			
Ch3. Problem of employee perception and attitude	Ch3St1			
.				
.				
.				
.				
Ch13. Lack of training, learning and development				

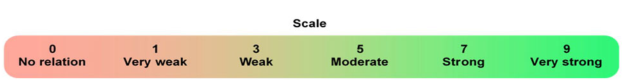


Fig. 8 Given scales

to overcome the challenges of m-Health service design in Bangladesh.

Table 13 displays each of the service design challenges in the row and strategies in the column. Using a scale from 0, where indicates no relationship, to '9', where shows a very strong relationship (shown in Fig. 8), please complete the relationship matrix to show the extent to which the strategies are effective in mitigating the stated challenges.

Table 14 The matrix of relationship between strategies and sustainability goals

Strategies (St)	Sustainability goals (SuS)			
	SuS1. Reducing the cost of health services	SuS2. Patients' satisfaction	SuS3. Accessibility to healthcare service to increase in the number of served patients	SuS4. Reducing environmental impact
St1. Forecast and plan for service demand	St1SuS1	St1SuS2	St1SuS3	
St2. Train employees	St2SuS1			
St3. Plan for contingencies and have a back-up plan for uncertainties	St3SuS1			
.				
.				
.				
.				
St13. Offer better service to recover the service				

Appendix E

Table 14 shows each of the service design strategies and sustainability goals. The strategies are listed in the rows and sustainability goals are listed in the columns. Using a scale from 0 to 9 (shown in Fig. 8), please complete the relationship matrix to show how each strategy relates to each sustainability goal.

Appendix F

Table 15 shows interrelationship of the strategies. Please fill the shaded cells based on the relationship between the strategies as strong relationship= S, medium relationship =M, weak relationship = W and no relationship = N. Please also mention the extend to which the interrelated strategies save cost and time. Please, follow the guidelines provided by the workshop coordinator to supply the information in the matrix.

Table 15 Interrelationships between the strategies

Strategies (St)	Strategies (St)							
	St1. Plan and forecast- service demand	St2. Train employees	St3. Plan for contingencies and have a back-up plan for uncertainties	St4. Improve awareness of the customers by extensive campaigns	St5. Innovate service through technology development	St6. Supply adequate logistical support	.	St13. Offer better service for better service recovery
St1. Service demand planning and forecasting								
St2. Imparting training to employees								
St3. Contingency planning and keeping back up for uncertainties								
St4. Improving awareness of the customers by extensive campaigns								
St5. Service innovation by technology development								
St6. Supply adequate logistical support								
.								
St13. Offer better service to recover the service								

Appendix G

See Fig. 9.

Appendix H

See Fig. 10.

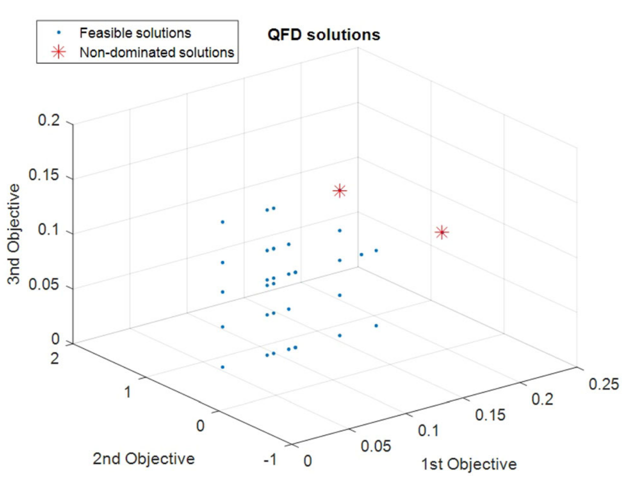


Fig. 9 Dominated and non-dominated solutions

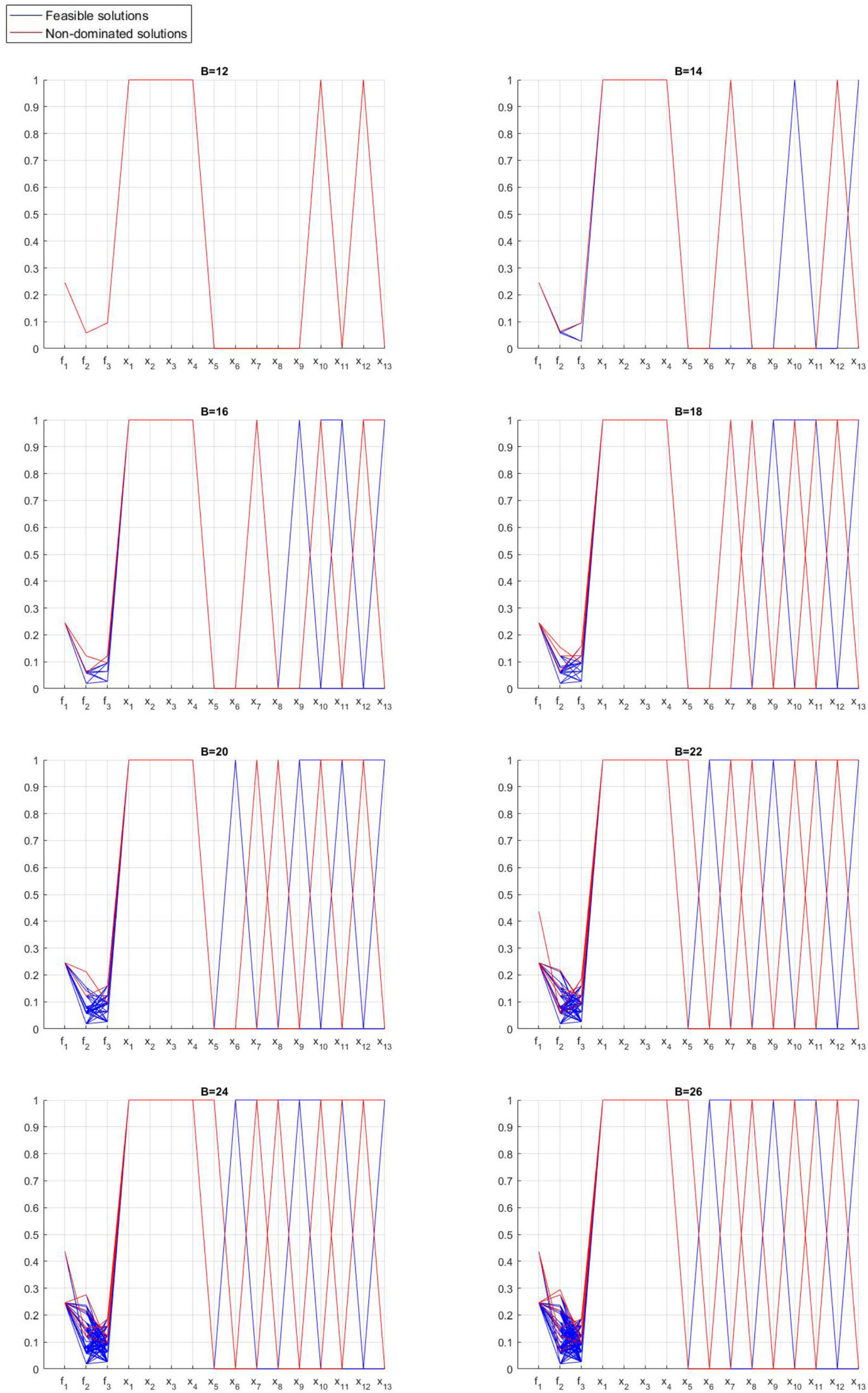


Fig. 10 Sensitivity analysis of *B* parameter including optimal amount of variables

Appendix I

See Fig. 11.

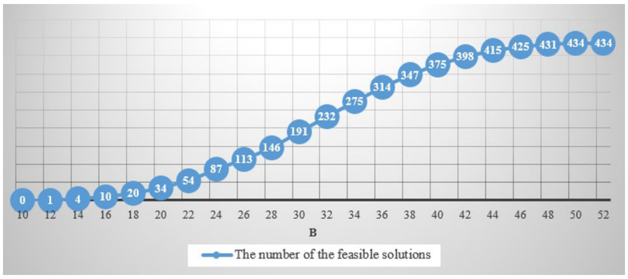


Fig. 11 Effect of *B* parameter on the quantity of QFD model's feasible solutions

Funding Open Access funding enabled and organized by CAUL and its Member Institutions. Open Access funding enabled and organized by CAUL and its Member Institutions. Open Access funding enabled and organized by CAUL and its Member Institutions. Open Access funding enabled and organized by CAUL and its Member Institutions. Open Access funding enabled and organized by CAUL and its Member Institutions. Open Access funding enabled and organized by CAUL and its Member Institutions. The author(s) received no financial support for this article.

Declaration

Conflict of interest The authors declare that they have no Conflict of interest.

References

Abdel-Basst, M., Mohamed, R., & Elhoseny, M. (2020). A novel framework to evaluate innovation value proposition for smart product-service systems. *Environmental Technology & Innovation, 20*, 101036.

Ahmed, T., Karmaker, C. L., Nasir, S. B., & Moktadir, M. A. (2023). Identifying and analysis of key flexible sustainable supply chain management strategies toward overcoming the post-covid-19 impacts. *International Journal of Emerging Markets, 18*(6), 1472–1492.

Akao, Y. (1990). *QFD: Integrating customer requirements into product design*. MA: Cambridge.

Ali, I., Arslan, A., Chowdhury, M., Khan, Z., & Tarba, S. Y. (2022). Reimagining global food value chains through effective resilience to covid-19 shocks and similar future events: A dynamic capability perspective. *Journal of Business Research, 141*, 1–12.

Aliahmadi, S. Z., Barzinpour, F., & Pishvaee, M. S. (2020). A fuzzy optimization approach to the capacitated node-routing problem for municipal solid waste collection with multiple tours: A case study. *Waste Management & Research, 38*(3), 279–290.

Aliahmadi, S. Z., Barzinpour, F., & Pishvaee, M. S. (2021). A novel bi-objective credibility-based fuzzy model for municipal waste collection with hard time windows. *Journal of Cleaner Production, 296*, 126364.

Anderson, L., & Ostrom, A. L. (2015). Transformative service research: Advancing our knowledge about service and well-being. *Journal of Service Research, 18*(3), 243–249.

Aurich, J. C., Mannweiler, C., & Schweitzer, E. (2010). How to design and offer services successfully. *CIRP Journal of Manufacturing Science and Technology, 2*(3), 136–143.

Becker, J., Beverungen, D. F., & Knackstedt, R. (2010). The challenge of conceptual modeling for product-service systems: Status-quo and perspectives for reference models and modeling languages. *Information Systems and e-business Management, 8*(1), 33–66.

Beuren, F. H., Ferreira, M. G. G., & Miguel, P. A. C. (2013). Product-service systems: A literature review on integrated products and services. *Journal of Cleaner Production, 47*, 222–231.

Biswas, D., Jalali, H., Ansaripoor, A. H., & De Giovanni, P. (2023). Traceability vs. sustainability in supply chains: The implications of blockchain. *European Journal of Operational Research, 305*(1), 128–147.

Bolton, R. N., & Lemon, K. N. (1999). A dynamic model of customers' usage of services: Usage as an antecedent and consequence of satisfaction. *Journal of Marketing Research, 36*(2), 171–186.

Burke, R. J. (2001). Supervision and service quality. *Measuring Business Excellence, 5*(4), 28–31.

Chae, B. K. (2012). An evolutionary framework for service innovation: Insights of complexity theory for service science. *International Journal of Production Economics, 135*(2), 813–822.

Chan, L. K., & Wu, M. L. (2002). Quality function deployment: A comprehensive review of its concepts and methods. *Quality Engineering, 15*(1), 23–35.

Chan, L. K., & Wu, M. L. (2002). Quality function deployment: A literature review. *European Journal of Operational Research, 143*(3), 463–497.

Chandler, J. D., & Lusch, R. F. (2015). Service systems: A broadened framework and research agenda on value propositions, engagement, and service experience. *Journal of Service Research, 18*(1), 6–22.

Chen, Z., Ming, X., Zhang, X., Yin, D., & Sun, Z. (2019). A rough-fuzzy dematel-anp method for evaluating sustainable value requirement of product service system. *Journal of Cleaner Production, 228*, 485–508.

Chou, C. J., Chen, C. W., & Conley, C. (2012). A systematic approach to generate service model for sustainability. *Journal of Cleaner Production, 29*, 173–187.

Chowdhury, M. M. H., Agarwal, R., & Quaddus, M. (2019). Dynamic capabilities for meeting stakeholders' sustainability requirements in supply chain. *Journal of Cleaner Production, 215*, 34–45.

Chowdhury, M. M. H., Chowdhury, P., Quaddus, M., Rahman, K. W., & Shahriar, S. (2024). Flexibility in enhancing supply chain resilience: Developing a resilience capability portfolio in the event of severe disruption. *Global Journal of Flexible Systems Management, 25*(2), 395–417.

Chowdhury, M.M.H., Paul, S.K., Khan, E.A., & Shakil Mahmud, A. (2024). A decision support model for barriers and optimal strategy design in sustainable humanitarian supply chain management. *Global Journal of Flexible Systems Management*, 25(3), 467–486.

Chowdhury, M. M. H., & Quaddus, M. (2016). Supply chain readiness, response and recovery for resilience. *Supply Chain Management: An International Journal, 21*(6), 709–731.

Chowdhury, M. M. H., & Quaddus, M. A. (2015). A multiple objective optimization based QFD approach for efficient resilient strategies to mitigate supply chain vulnerabilities: The case of garment industry of bangladesh. *Omega, 57*, 5–21.

Chowdhury, M. M. H., & Quaddus, M. A. (2016). A multi-phased QFD based optimization approach to sustainable service design. *International Journal of Production Economics, 171*, 165–178.

Chowdhury, M. M. H., & Quaddus, M. A. (2021). Supply chain sustainability practices and governance for mitigating sustainability risk and improving market performance: A dynamic capability perspective. *Journal of Cleaner Production, 278*, 123521.

Christopher, M., & Lee, H. (2004). Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management, 34*(5), 388–396.

da Costa Fernandes, S., Pigosso, D. C., McAloone, T. C., & Rozenfeld, H. (2020). Towards product-service system oriented to circular economy: A systematic review of value proposition design approaches. *Journal of Cleaner Production, 257*, 120507.

Dai, J., & Blackhurst, J. (2012). A four-phase AHP-QFD approach for supplier assessment: A sustainability perspective. *International Journal of Production Research, 50*(19), 5474–5490.

Darko, A., Chan, A. P. C., Ameyaw, E. E., Owusu, E. K., Pärn, E., & Edwards, D. J. (2019). Review of application of analytic hierarchy process (AHP) in construction. *International Journal of Construction Management, 19*(5), 436–452.

Darzi Ramandi, M., Bafruei, M. K., Ansaripoor, A. H., Paul, S. K., & Chowdhury, M. M. H. (2023). Coordination mechanisms in a two-stage green supply chain: analyzing the impact of transportation decisions on environment. *International Transactions in Operational Research, 30*(6), 4170–4207.

Delice, E. K., & Güngör, Z. (2011). A mixed integer goal programming model for discrete values of design requirements in qfd. *International Journal of Production Research, 49*(10), 2941–2957.

Derissen, S., Quaas, M. F., & Baumgärtner, S. (2011). The relationship between resilience and sustainability of ecological-economic systems. *Ecological Economics, 70*(6), 1121–1128.

Dwivedi, A., Agrawal, D., Jha, A., Gastaldi, M., Paul, S. K., & D'Adamo, I. (2021). Addressing the challenges to sustainable initiatives in value chain flexibility: Implications for sustainable development goals. *Global Journal of Flexible Systems Management,* 22 (Suppl 2), S179–S197.

Faisal, M. N. (2013). Managing risk in small and medium enterprises (SMES) supply chains' using quality function deployment (QFD) approach. *International Journal of Operations Research and Information Systems (IJORIS), 4*(1), 64–83.

Fasoli, D., & Panzeri, S. (2019). Optimized brute-force algorithms for the bifurcation analysis of a binary neural network model. *Physical Review E, 99*(1), 012316.

Fiksel, J. (2003). Designing resilient, sustainable systems. *Environmental Science & Technology, 37*(23), 5330–5339.

Fiksel, J. (2006). Sustainability and resilience: Toward a systems approach. *Sustainability: Science, Practice and Policy, 2*(2), 14–21.

Freire, K., Sangiorgi, D., et al. (2010). Service design and healthcare innovation: From consumption to co-production to co-creation. In *Proceedings of 2nd service design and service innovation conference, servdes*. 2010 (pp. 39–50).

Fulzele, V., Shankar, R., & Choudhary, D. (2019). A model for the selection of transportation modes in the context of sustainable freight transportation. *Industrial Management & Data Systems, 119*(8), 1764–1784.

Gerstner, E., & Libai, B. (2006). Invited commentary-why does poor service prevail? *Marketing Science, 25*(6), 601–603.

Goldstein, S. M., Johnston, R., Duffy, J., & Rao, J. (2002). The service concept: The missing link in service design research? *Journal of Operations management, 20*(2), 121–134.

Gupta, N., Gunawan, I., & Kamineni, R. (2024). Analysing resilience and leagility in post-pandemic sustainable supply chain management: A systematic literature review. *Built Environment Project and Asset Management*.

Haji, M., & Himpel, F. (2024). Building resilience in food security: Sustainable strategies post-covid-19. *Sustainability, 16*(3), 995.

Hauser, J. R., Clausing, D., et al. (1988). The house of quality. *Sloan Management Review*, 63–73,

Hazée, S., Van Vaerenbergh, Y., Delcourt, C., & Kabadayi, S. (2020). Service delivery system design for risk management in sharing-based product service systems: A customer-oriented approach. *International Journal of Operations & Production Management, 40*(4), 459–479.

Ivanov, D. (2018). Revealing interfaces of supply chain resilience and sustainability: A simulation study. *International Journal of Production Research, 56*(10), 3507–3523.

Ivanov, D. (2021). Correction to: Viable supply chain model: Integrating agility, resilience and sustainability perspectives-lessons from and thinking beyond the covid-19 pandemic. *Annals of Operations Research* 1–2,

Ivanov, D. (2024). Transformation of supply chain resilience research through the covid-19 pandemic. *International Journal of Production Research*, 1–22,

Ivanov, D., & Dolgui, A. (2020). Viability of intertwined supply networks: Extending the supply chain resilience angles towards survivability. A position paper motivated by covid-19 outbreak. *International Journal of Production Research, 58*(10), 2904–2915.

Ivanov, D., & Dolgui, A. (2022). Stress testing supply chains and creating viable ecosystems. *Operations Management Research, 15*(1), 475–486.

Jain, T., & Hazra, J. (2020). Optimal regulation and sustainable product design under uncertainties. *International Journal of Production Economics, 225*, 107574.

Johnson, E., & Lee, D. (2023). Integrated service design: Leveraging digital transformation for sustainable practices. *Sustainability, 15*(3), 450–470.

Karsak, E. E. (2004). Fuzzy multiple objective programming framework to prioritize design requirements in quality function deployment. *Computers & Industrial Engineering, 47*(2–3), 149–163.

Keoleian, G. A., & Menerey, D. (1994). Sustainable development by design: Review of life cycle design and related approaches. *Air & Waste, 44*(5), 645–668.

Kumar, V., Vrat, P., & Shankar, R. (2022). Factors influencing the implementation of industry 4.0 for sustainability in manufacturing. *Global Journal of Flexible Systems Management*, *23*(4), 453-478.

Lam, H. Y., Ho, G. T. S., Mo, D. Y., & Tang, V. (2021). Enhancing data-driven elderly appointment services in domestic care communities under covid-19. *Industrial Management & Data Systems, 121*(7), 1552–1576.

Leite, H., & Hodgkinson, I. R. (2023). Examining resilience across a service ecosystem under crisis. *Public Management Review, 25*(4), 690–709.

Liu, J., Pacitti, E., Valduriez, P., De Oliveira, D., & Mattoso, M. (2016). Multi-objective scheduling of scientific workflows in multisite clouds. *Future Generation Computer Systems, 63*, 76–95.

Mangla, S. K., Kumar, P., & Barua, M. K. (2014). A flexible decision framework for building risk mitigation strategies in green supply chain using sap-lap and IRP approaches. *Global Journal of Flexible Systems Management,* 15(3), 203–218.

Martin, K. D., & Hill, R. P. (2015). Saving and well-being at the base of the pyramid: Implications for transformative financial services delivery. *Journal of Service Research, 18*(3), 405–421.

McLellan, B., Zhang, Q., Farzaneh, H., Utama, N. A., & Ishihara, K. N. (2012). Resilience, sustainability and risk management: A focus on energy. *Challenges, 3*(2), 153–182.

Milgate, M. (2001). Supply chain complexity and delivery performance: An international exploratory study. *Supply Chain Management: An International Journal, 6*(3), 106–118.

Mishra, A., Gupta, N., & Jha, G.K. (2024). Supply chain resilience: Adapting to global disruptions and uncertainty. *International Journal of Innovative Research in Engineering*

Mishra, A., Soni, G., Ramtiyal, B., Dhaundiyal, M., Kumar, A., Sarma, P. (2023). Building risk mitigation strategies for circularity adoption in indian textile supply chains. *Annals of Operations Research*, 1–36.

Mishra, N. K., Pande Sharma, P., & Chaudhary, S. K. (2024). Redefining agile supply chain practices in the disruptive era: A case study identifying vital dimensions and factors. *Journal of Global Operations and Strategic Sourcing*.

Mohammed, A. (2020). Towards 'gresilient' supply chain management: A quantitative study. *Resources, Conservation and Recycling, 155*, 104641.

Mohammed, A., Harris, I., Soroka, A., Naim, M., Ramjaun, T., & Yazdani, M. (2021). Gresilient supplier assessment and order allocation planning. *Annals of Operations Research, 296*(1), 335–362.

Mohammed, A., Jabbour, A. B. L. D. S., & Diabat, A. (2023). Covid-19 pandemic disruption: A matter of building companies' internal and external resilience. *International Journal of Production Research, 61*(8), 2716–2737.

Nasir, S. B., Ahmed, T., Karmaker, C. L., Ali, S. M., Paul, S. K., & Majumdar, A. (2022). Supply chain viability in the context of covid-19 pandemic in small and medium-sized enterprises: implications for sustainable development goals. *Journal of Enterprise Information Management, 35*(1), 100–124.

Negash, Y. T., Sarmiento, L. S. C., Tseng, M. L., Jantarakolica, K., & Tan, K. (2021). Sustainable product-service system hierarchical framework under uncertainties: The pharmaceutical industry in ecuador. *Journal of Cleaner Production, 294*, 126188.

Newman, K. (2001). Interrogating servqual: A critical assessment of service quality measurement in a high street retail bank. *International Journal of Bank Marketing, 19*(3), 126–139.

Nyoman Pujawan, I., & Geraldin, L. H. (2009). House of risk: A model for proactive supply chain risk management. *Business Process Management Journal, 15*(6), 953–967.

O'Brien, J., Fossey, E., & Palmer, V. J. (2021). A scoping review of the use of co-design methods with culturally and linguistically diverse communities to improve or adapt mental health services. *Health & Social Care in the Community, 29*(1), 1–17.

Park, T., & Kim, K. J. (1998). Determination of an optimal set of design requirements using house of quality. *Journal of Operations Management, 16*(5), 569–581.

Pettit, T. J., Croxton, K. L., & Fiksel, J. (2013). Ensuring supply chain resilience: Development and implementation of an assessment tool. *Journal of Business Logistics, 34*(1), 46–76.

Piila, N., & Sarja, M. (2024). Extraordinary supply chain disruptions and the circular economy transition in the construction industry–an opportunity within crisis? Sustainable Production and Consumption.

Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. *The International Journal of Logistics Management, 20*(1), 124–143.

Rahman, T., Moktadir, M. A., & Paul, S. K. (2022). Key performance indicators for a sustainable recovery strategy in health-care supply chains: Covid-19 pandemic perspective. *Journal of Asia Business Studies, 16*(3), 472–494.

Rajesh, R. (2021). Flexible business strategies to enhance resilience in manufacturing supply chains: An empirical study. *Journal of Manufacturing Systems, 60*, 903–919.

Ramandi, M. D., & Bafruei, M. K. (2019). Coordinating replenishment decisions in a decentralized two-echelon supply chain using by revenue sharing contract. In *2019 15th Iran international industrial engineering conference (IIIEC)*, (pp. 297–304).

Ramandi, M. D., & Bafruei, M. K. (2020). Effects of government's policy on supply chain coordination with a periodic review inventory system to reduce greenhouse gas emissions. *Computers & Industrial Engineering, 148*, 106756.

Robert, L., & Malandain, G. (1998). Fast binary image processing using binary decision diagrams. *Computer Vision and Image Understanding, 72*(1), 1–9.

Ruel, S., El Baz, J., Ivanov, D., & Das, A. (2021). Supply chain viability: conceptualization, measurement, and nomological validation. *Annals of Operations Research*. 1–30.

SadeghZadeh, H., Ansaripoor, A.H., & Oloruntoba, R. (2023). The role of blockchain in developing supply chain resilience against disruptions. Supply chain risk and disruption management: Latest tools, techniques and management approaches (pp. 117–140). Springer.

Saha, P., Talapatra, S., Belal, H. M., & Jackson, V. (2022). Unleashing the Potential of the TQM and Industry 4.0 to Achieve Sustainability Performance in the Context of a Developing Country. *Global Journal of Flexible Systems Management*, *23*(4), 495-513.

Sánchez-García, J. Y., Núñez-Ríos, J. E., López-Hernández, C., & Rodríguez-Magaña, A. (2023). Modeling organizational resilience in SMEs: A system dynamics approach. *Global Journal of Flexible Systems Management*, *24*(1), 29-50.

Serdarasan, S. (2013). A review of supply chain complexity drivers. *Computers & Industrial Engineering, 66*(3), 533–540.

Smith, J., & Brown, M. (2023). Adaptive service design framework: Enhancing agility and rapid response mechanisms. *Journal of Service Research, 45*(2), 215–230.

Taylor, R., & Kim, J. (2023). Post-pandemic service strategies: Key factors for resilient delivery. *International Journal of Service Industry Management, 34*(4), 600–620.

Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal, 28*(13), 1319–1350.

Traore, B. B., Kamsu Foguem, B., Tangara, F., & Desforges, X. (2019). Service-oriented computing for intelligent train maintenance. *Enterprise Information Systems, 13*(1), 63–86.

Travis, P., Bennett, S., Haines, A., Pang, T., Bhutta, Z., Hyder, A. A., & Evans, T. (2004). Overcoming health-systems constraints to achieve the millennium development goals. *The Lancet, 364*(9437), 900–906.

Tushar, S. R., Moktadir, M. A., Kusi-Sarpong, S., & Ren, J. (2023). Driving sustainable healthcare service management in the hospital sector. *Journal of Cleaner Production, 420*, 138310.

Usaid, T. R. (2012). *mhealth compendium*. Washington DC: USAID.

Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. *European Journal of Operational Research, 169*(1), 1–29.

Vargo, S. L., & Lusch, R. F. (2014). Evolving to a new dominant logic for marketing. *Journal of Marketing, 68*(1), 1–17.

Villar, A., Abowitz, S., Read, R., & Butler, J. (2024). Maximizing supply chain resilience: Viability of a distributed manufacturing

network platform using the open knowledge resilience framework. Operations research forum, vol. 5, (pp. 1–41).
Wang, H., Xie, M., & Goh, T. N. (1998). A comparative study of the prioritization matrix method and the analytic hierarchy process technique in quality function deployment. *Total Quality Management, 9*(6), 421–430.
Wang, M., & Yao, J. (2023). Intertwined supply network design under facility and transportation disruption from the viability perspective. *International Journal of Production Research, 61*(8), 2513–2543.
Wasserman, G. S. (1993). On how to prioritize design requirements during the QFD planning process. *IIE Transactions, 25*(3), 59–65.
Wolniak, E. R., & Sedek, A. (2009). Using QFD method for the ecological designing of products and services. *Quality & Quantity, 43*(4), 695–701.
Yang, M., & Evans, S. (2019). Product-service system business model archetypes and sustainability. *Journal of Cleaner Production, 220*, 1156–1166.
Zekhnini, K., Cherrafi, A., Bouhaddou, I., Chaouni Benabdellah, A., & Bag, S. (2022). A model integrating lean and green practices for viable, sustainable, and digital supply chain performance. *International Journal of Production Research, 60*(21), 6529–6555.

Key Questions

1. What are the key challenges in designing a resilient and sustainable service system?
2. How can resilience attributes (readiness, response, and recovery) be integrated with sustainability goals (people, profit, and planet) in service system design?
3. What strategies can be adopted to mitigate disruptions while ensuring long-term sustainability?

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 resilience, sustainability, decarbonization, disruptive technologies, and their implications on supply chain management.

Seyed Zeinab Aliahmadi is a PhD candidate in Industrial Engineering at Department of Systems Engineering, École de Technologie Supérieure (ÉTS), University of Québec, Canada. Her area of research is on the optimization approaches, Industry 4.0 technologies, sustainability pillars, and circular economy principles in supply chain strategies. She has published several research papers in leading international journals like Cleaner Production, and Waste Management and Research. The main focus of her papers is on operation management, uncertainty approaches, metaheuristic algorithms, and multi-objective programming.

Mohammed A. Quaddus is currently working as a professor at the School of Management and Marketing at Curtin University, Perth. Prof Quaddus has research interest in multiple disciplines, which include Behavioural Modelling in Marketing and Tourism, ICT and Tourism, Sustainability and Tourism, Information Systems Planning, Logistics and Supply Chain Management, Risk Management in Supply Chain. Prof Quaddus has published over 300 papers in refereed journals, international conferences, and chapters in Books. His publications have appeared in Omega, International Journal of Production Economics, European Journal of Information Systems, Decision Support Systems, Supply Chain Management—An International Journal, Information System Frontiers, Rural Sociology, among many others. He has successfully supervised over 60 doctoral students. In 1996 and 2005, he received "researcher of the year" award in Curtin Business School. From Jan 2009 to Dec 2011, he was deputy dean and dean of research, and from March 2013 to March 2014, he was Director of Curtin Graduate School of Business, Curtin Business School. Prof Quaddus also acted as consultants for a number of organizations including DAFWA, Woodside Petroleum, and World Bank.

Amir H. Ansaripoor is a Senior Lecturer in the School of Management and Marketing at Curtin University where he joined in 2015. He holds a Ph.D. degree in Business Administration with a specialisation in Operations Management and Decision Sciences from ESSEC Business School (France and Singapore). Amir's research interests mainly are based on using Operations Research and Business Analytics techniques in solving complex problems in different applications including but not limited to Risk Management, Supply Chain Management, Logistics, Fleet Management, Agriculture, Finance, Energy, and Environment. His research has been published in top-tier journals such as the European Journal of Operational Research, Transportation Research Part C, and International Journal of Production Economics.

Seyedali Mirjalili is a Professor at the Center for Artificial Intelligence Research and Optimization at Torrens University. He has gained international recognition for his contributions to nature-inspired artificial intelligence techniques, with over 600 published works that have received more than 110,000 citations and an H-index of 115. He has been on the list of the top 1% of highly cited researchers since 2019, and Web of Science named him one of the most influential researchers in the world. In 2022 and 2023, the Australian newspaper recognized him as a global leader in Artificial Intelligence and a national leader in the Evolutionary Computation and Fuzzy Systems fields. He serves as a senior member of IEEE and holds editorial positions at several top AI journals, including Engineering Applications of Artificial Intelligence, Applied Soft Computing, Neurocomputing, Advances in Engineering Software, Computers in Biology and Medicine, Healthcare Analytics, Applied Intelligence, and Decision Analytics.