A hybrid framework to model resilience in the generic medicine supply chain of MSMEs

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A hybrid framework to model resilience in the generic medicine supply chain of MSMEs

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Abstract

Purpose – One of the most important components of healthcare is the timely delivery of pharmaceutical products, such as life-saving medicines. However, disruptions like COVID-19 bring new challenges and risks to the pharmaceutical supply chain (PSC) and healthcare organizations that impact their operational performance. This study focuses on mitigating risks in India's generic medicine supply chain (GMSC) as a result of various disruptions, which can assist policymakers develop appropriate plans and strategies to build resilience in the Jan Aushadhi Scheme (JAS) of micro, small and medium enterprises (MSMEs) in order to improve their overall performance.

Design/methodology/approach – Risk-causing vulnerabilities and resilience capabilities are identified from the literature review and expert's opinions. Following that, the vulnerabilities are classified into cause-and-effect vulnerabilities, and supply chain resilient capabilities (SCRCs) are measured using a hybrid fuzzy DEMATEL and best worst method (FDEMATEL-BMW) framework.

Findings – The outcome of the study reveals that transportation breakdown, loss of human resources and loss of suppliers are the potential risk-causing vulnerabilities that lead to vulnerabilities like shortages of medicines, loss of in-hand stock qualities and loss of sales/revenue. In addition, the analysis suggests that the sustainability of an organization with maximum weightage is the critical factor for building resilience in GMSC followed by flexibility, agility and visibility.

Practical implications – The integration of resilience into Jan Aushadhi GMSC can help in managing disruptions efficiently and effectively to mitigate risk and optimize MSMEs overall performance.

Originality/value – To the best of the authors' knowledge, this work will be the first of its kind to model resilience in GMSC of MSMEs using a hybrid framework.

Keywords Resilience, Supply chain, COVID-19, Generic medicine, MCDM, Fuzzy DEMATEL, BWM

Paper type Research paper

1. Introduction

According to the Indian Economic Survey report 2021 (Pharmaceutical Industry Report, 2021), the pharmaceutical domestic market is expected to reach 120–130 billion USD by 2030. Today, India is the 12th largest exporter of medical goods globally and is listed among the largest provider of generic medicines, accounting for 20% of global export volume. India fulfills the demand of about 40% of generic medicines in the US and 25% of all medicines in the UK. Despite being one of the world's leading suppliers, the popularity and consumption of generic medications in India remain low due to issues such as unavailability, and lack of trust in the quality of the medicine by the patients (Das *et al.*, 2017). To improve the availability of generic medicines in India and gain patients' trust, the Government of India (GoI) launched the Jan Aushadhi Scheme (JAS), which intends to provide low-cost affordable generic medicines to all sections of the country. Individuals with a pharmaceutical background in

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their educational qualifications are eligible for initial financial assistance to create a customized Jan Aushadhi store under the scheme. Today, JAS is associated with many generic medicine suppliers to meet the need of all their established retail stores and some other private distribution agencies through its supply chain, allowing for easy procurement and delivery operations. To further strengthen the distribution and consumption of generic medicines, the scheme also provides support to various micro, small and medium enterprises (MSMEs) in the country.

Today, MSMEs provide a major contribution to the economic development of a country (Gunasekaran *et al.*, 2011). As a result, policymakers must pay special attention to MSMEs to ensure their success. However, it is anticipated that in future, uncertainties such as the COVID-19 pandemic could increase the risks associated with the failure of the entire or a portion of MSMEs supply chain activities. Due to the advent of these disruptions, MSMEs GMSC must adopt comprehensive risk-mitigation strategies in future. Without proper supply chain risk mitigation strategies, the continual efforts of healthcare workers may go in vain. In order to accomplish this, supply chain resilience might be a solution that enables a swift recovery from disruptions, accidents, disturbances and natural disasters (Kumar and Anbanandam, 2019). Integration of the supply chain with resilience could provide an opportunity for the decision-makers to deal with systemic disruptions and disasters. The resilience supply chain is the concept that incorporates characteristics like adaptive capabilities, quick readiness and response to threats and disruptions (Kaviani *et al.*, 2020). Hence, resilience is a multidisciplinary concept that evolved and is designed to absorb shock and perform quick recovery actions to return to its original status (Papadopoulos *et al.*, 2017; Siva Kumar and Anbanandam, 2020; Bastani *et al.*, 2021a, b). The definition of a resilient supply chain lacks cost-effectiveness at the operational level. However, the World Economic Forum report of 2013 indicates the coexistence of cost-effectiveness with resilience (Bhatia, 2013). Sustained resilience in the supply chain ensures the mitigations of vulnerabilities by using the inbuilt capabilities of the supply chain.

In addition to speedy recovery in the face of uncertainty, the resilient supply chain develops the capability for continuous improvement by analyzing the company's strengths and weaknesses, opportunities and threats (Ponomarov and Holcomb, 2009). The resilience supply chain has four major aspects that include preparations for the disruptions in the system in advance, quick response to the sudden uncertainties, recovery actions against the disruptions caused and continuous growth maintenance to be in competitive advantage (Tukamuhabwa *et al.*, 2015). Among the supply chain of various healthcare products, the pharmaceutical sector is one of the complex supply chain that needs an effective formulation of resilience-based study to handle uncertain situations (Karmaker and Ahmed, 2020). In addition to complexities in pharmaceutical supply chain (PSC), any unexpected vulnerabilities (either external, e.g. natural disasters, pandemics, theft, or internal like labor strikes, technology faults and expiry of in-hand stocks of drugs) could result in significant loss to the supply chain. Thus, PSC must adopt an integrated resilience approach so that it can respond more quickly and cost-efficiently during unpredictable situations (Zahiri *et al.*, 2017). Though many studies emphasize on developing a robust PSC, to the best of our knowledge, no such study exists that focuses on the GMSC of MSMEs in India. As a result, the following research questions are posed:

RQ1. What are the vulnerabilities associated with GMSC of MSMEs?

RQ2. What are the driving and dependent vulnerabilities in the GMSC of MSMEs?

RQ3. What are the significant resilient capabilities of a GMSC of MSMEs?

RQ4. How to formulate the risk mitigation strategies based on vulnerabilities of GMSC and capabilities of resilience?

We design a framework that comprises two methodologies – fuzzy DEMATEL (FDEMATEL) and best worst method (BWM). We call this framework a hybrid FDEMATEL-BMW framework to answer our research questions. While there are other qualitative and multi-criteria decision-making (MCDM) techniques for addressing uncertainty in decision-making, building interrelationships among factors and prioritizing them, we chose FDEMTAEL and BWM for two primary reasons. First, we seek to show the interrelationship between factors, and DEMATEL delivers better results than interpretive structural modeling (ISM) since its total-relation matrix contains more information than the reachability matrix of ISM. Moreover, the construction of ISM's reachability matrix is rather complicated, whereas DEMATEL's computational steps are significantly simpler. The purpose of linking fuzzy to DEMATEL is that fuzzy set theory can handle vague judgments mathematically, therefore measuring qualitative factors with fuzzy numbers enables more realistic capture of judgements to improve the decision-making results (Mavi and Standing, 2018; Chen, 2021). Second, our objective is to prioritize the resilient capabilities, for which we use the BWM method. Rezaei (2016) shows that in a real-world scenario, BWM outperforms analytic hierarchy process (AHP) or other MCDM in terms of consistency ratio, as well as other metrics like a minimum violation, total deviation and conformity. This methodology has also been applied to real-world problems such as locating freight transit from outstations to airports. In another study, BWM has been utilized for investigating the social sustainability of the supply chain in a manufacturing company (Badri Ahmadi *et al.*, 2017). Thus, we design a hybrid framework by selecting FDEMATEL and BWM methodologies in our study.

In the first step, we gather important data on risk-causing vulnerabilities and resilience capabilities from the literature and various industries that is the implementing agency of JAS. The vulnerabilities are then classified as cause-and-effect vulnerabilities using FDEMATEL, which depicts the inter-relationships between them. The supply chain resilient capabilities (SCRCs) are then derived using BWM, which prioritizes resilience capabilities in GMSC to assist decision-makers in formulating risk-reduction plans and focusing on the most critical capabilities to import resilience. Finally, based on the findings of the study, we offer an additional framework for designing resilient GMSC. The framework lays out a road map for integrating resilience capabilities into every aspect of GMSC, potentially leading to the creation of RGMSC. The findings of this study can guide the top management and policy-makers of JAS in adopting RGMSC concepts. The finding can also be helpful for the decision-makers of GMSC of MSMEs to understand the inter-relationships among the vulnerabilities and focus more on the most significant capabilities of resilient generic pharmaceutical supply chain (RGPSC).

The rest of the paper is organized as follows: Section 2 discusses the literature review. Methods in Section 3 show the steps to finalize risk-causing vulnerabilities and SCRCs. A detailed description of vulnerabilities and SCRCs is shown in Section 4. The research framework and analysis are presented in Section 5. Finally, discussions of results are presented in Section 6 with conclusions, limitations and future scope in Section 7.

2. Literature review

In this section, we review the literature on resilience and PSC, identify research gaps, and outline our major contributions to the existing literature. In recent years, resilient supply chain has gained interest in research community since it can manage environmental fickleness (Pettit *et al.*, 2019). Resilience is the term derived from material science of engineering background that is defined as the ability of restrained body to recover its original condition quickly. Another way of defining resilience is adopted in ecological system where species can adapt according to environmental instabilities. The industrialist accepted the definition of resilience as ability of an enterprise to sustain and grow by continuous adaptation after facing turbulence. Turbulence in the system creates disruptions that requires quick recovery actions as it can influence the SC operations (Pettit *et al.*, 2010). Risks in the SC are unavoidable, therefore proactive strategies to tackle risks become significant. SC risks are classified as operational as well as disruptive risk. Operational risks are associated with frequent business risks, lead time delays and demand fluctuations whereas, disruptive risks harder to predict and are less frequent but comes with higher impact on the system. For instance, COVID-19 comes as one of worst disruptive risk that humankind faces recently that results into huge shortages and delays in healthcare as well as all other types of supply chain. Hence, disruptive risks ignited the need of resilience supply chain in different field of supply chain (Shishodia *et al.*, 2021). Resilience supply chain could provide competitive advantage as it acts proactively and design supply chain for unexpected disruptions (Novak *et al.*, 2021). To attain resilience, supply chain needed to be more transparent and a collaborative approach is required to handle turbulence (Hemant *et al.*, 2022). The literature shows a very few attempts have been made to transfer resilience in ecological supply chain (Wieland and Durach, 2021).

2.1 Resilience and pharmaceutical supply chain

Resilience is an effective strategy for healthcare management, especially for the pharmaceutical sector, which helps to respond quickly during disasters and turbulence like pandemics (Bastani *et al.*, 2021a, b). The role of resilience in the PSC is emphasized as it provides an opportunity to recover and return to the initial condition, even in a more optimal situation. Moreover, it can predict the probable causes of vulnerabilities and threats and stop the probability of reoccurrence. The theoretical framework suggests that headship, governance, financing, health personnel, information service delivery and medical products are the key issues that can influence the health system's resilience. Some literature explores the prominent role of resilience in the healthcare supply chain in the public sector when it faces disruptions during the pandemic and provides learnings for future readiness and learnings to achieve recovery (Scala and Lindsay, 2021). The studies highlighted various enablers of a resilient supply chain named as agility, robustness, redundancy, collaborations, knowledge management, adaptability, flexibility and visibility (Hohenstein *et al.*, 2015; Ali *et al.*, 2017). The research findings show that supply chain capabilities need improvement to get resilience, particularly flexible sourcing, order fulfillments, visibility and collaborations in the pharmaceutical sector (Ward and Hargaden, 2019). The other research findings revealed four dimensions of supply chain vulnerabilities turbulence, external pressure, sensitivity and connectivity with six supply chain capabilities dimensions as flexibility, visibility, collaborations, adaptation, reserve capacity and supplier dispersity based on a survey in the pharmaceutical industry (Ward and Hargaden, 2019). The study also denotes that the supplier's percentage uptime and disruption nature are the main determinants of strategies for mitigations.

Partial sourcing and reliable supplier can be optimal for relief if unreliable suppliers possess a limited capacity. In addition to that, rerouting contingent planning is a tactic if reliable suppliers can provide volume flexibility (Tomlin, 2006). Tang points out that a robust supply chain with integrated contingency planning can face disruptions more efficiently and establish a more resilient firm (Tang, 2006). Bastani *et al.* (2021a, b) identified nine main 26 subthemes strategies in PSC like revisions of healthcare management and policies, more supervisions, privatizations and strategic purchasing to improve resilience level in the PSC. The pilot study suggests a correlation between the performance of a firm and increased resilience. The researchers developed a tool for measuring supply chain resilience titled supply chain resilience assessment and management (SCRAM). The study uncovered the linkages between the vulnerabilities present in the system and its capabilities (Pettit *et al.*, 2013). Gonzalez (2016) proposed a model to tackle risks and disruptions based on three categories of indicators to attain organizational resilience, business resilience and ultimately labor resilience. Karl *et al.* (2018) reported that order and delivery lead time, supplier delivery efficiency, on-time delivery and customer satisfaction significantly influence a resilient supply chain. Table 1 discusses the important contributions of researchers in modeling resilience PSC.

2.2 Research gaps and contributions

The previous work on resilience PSC provides a broad range of insights for the researchers in three main domains. First, it establishes a connection between potential PSC vulnerabilities. Second, it evaluates the resilience capabilities for risk mitigation during uncertain periods such as the COVID-19 pandemic. Third, it emphasizes on supply chain elements such as the need for sustainability, visibility and adaptability in the face of sudden risk. However, to the best of our knowledge, no study is available that focuses on building resilience in GMSC for MSMEs in the Indian context. Moreover, while a few studies employ the MCDM framework to explore resilient PSC, the same is missing in GMSC. Thus, we make the following contributions to the existing literature:

(1) We identify seven risk-causing vulnerabilities in GMSC of MSMEs in the Indian Context.

(2) We propose nine SCRCs in GMSC to mitigate risk and optimize the system's overall performance.

(3) One of our main contributions is the identification of cause-and-effect vulnerabilities and the prioritization of SCRCs using the FDEMATEL-BMW framework, which minimizes the time and effort of the decision-makers to focus on major risk-causing vulnerabilities and SCRCs.

3. Methods

In this study, two-stage methods are employed to identify risk-causing vulnerabilities and SCRCs. First, a systematic literature review is performed to extract relevant papers that discuss vulnerabilities and resilience capabilities in GMSC. Next, experts' opinions are collected to gather information on real field issues in the GMSC of MSMEs in India. The steps in the two-stage processes are shown below.

3.1 Search strategy and data finalization

First, important databases, which include Scopus, Web of Science (WoS) and PubMed are selected due to the availability of a wide range of articles like research and conference papers, book chapters and white papers in the field of medicine and supply chain. From the selected databases, journals such as *Omega*, *International Journal of Production Economics*, *Benchmarking: An International Journal, Journal of Supply Chain Management*, *Technological Forecasting and Social Change*, *Expert Review of Vaccine*s, *BMC Health Services*, etc. are identified as relevant for the study. Next, we use the following criteria using the AND operator to extract the articles: PSC and resilience are chosen as the primary keywords, the time-span is 1990–2022, published in peer-reviewed international journals, and the language is English. The results of the extracted articles using various combinations of keywords with different operators are shown in Table 2. As pharmaceutical is a broad area, the above-mentioned procedures aim to refine and narrow down the area to focus on a predefined, constricted and research-oriented approach. The literature code tree is shown in

S. N	References	Description
1	Sabouhi *et al.* (2018)	The study used data envelopment analysis (DEA) to design a resilient supply chain and validated the proposed model with resilient strategies
2	Pettit *et al.* (2013)	Exploratory assessment of resilient supply chain in the pharmaceutical supply chain is done by validating validated approach, i.e. the supply chain risk assessment method (SCRAM). The results show that there are various supply chain capabilities like flexibility insourcing, flexibility in order fulfillment, visibility and collaborations required for resilience
3	Yaroson *et al.* (2019)	This paper explores the impact of resilience on dynamic disruptions in the supply chain by investigating the literature. The research shows that alertness, connectivity and visibility are the dimensions of agility that can reduce the shortage of drugs
4	Yaroson *et al.* (2021)	The results illustrated the complex adaptive system (CAS) that provides a method to understand resilient PSC, including elements like environment, vulnerabilities and PSC strategies
5	Blos *et al.* (2015)	The study develops a general supply chain business continuity framework for pharmaceutical supply chain risks in the business unit of Iran
6	Lücker and Seifert (2017)	The paper study was based on finding relationships among three key operational risk measures: risk mitigation inventory (RMI), dual sourcing and agility capacity within a drug production firm exposed to disruptions. The results show that RMI levels decrease in the presence of the other two strategies. The research introduced an operational metric that quantifies resilient supply chains. Furthermore, it shows supply chain disruptions impacted severely on business and hence should be appropriately managed
7	He *et al.* (2022)	This paper presented two-echelon dual marketing supply chain channels for one pharmaceutical firm exposed to risk, one without risk exposure and one retailer. Three sub-models are developed: single coalition structure, double coalition structure and multi-party coalition structure whose profits are investigated
8	Derqui *et al.* (2021)	It is based on an exploratory analysis of community pharmacies in Spain that measures the interrelationship of sustainability practices in the COVID-19 pandemic. The results stated that future health crisis resilience could be incorporated into the system by implementing sustainability practices in community pharmacies
9	Zeraati Foulolaei *et al.* (2017)	The study focuses on information technology capabilities' impact on the performance of the pharmaceutical organization in Iran. The research findings show that technological capabilities are effective on purity, resilience and agility and positively impact organizational performance
10	Huang *et al.* (2018)	The paper introduced the concept of drug traceability using blockchain technology and created a drug ledger. According to the study, drug ledger is a more resilient, stable and acceptable blockchain storage
11	Hannan *et al.* (2021)	The study shows how healthcare is responding to sudden changes in operations due to risks associated with the COVID-19 pandemic
12	Salehi *et al.* (2020)	The study is based on the resilience engineering concept implemented for performance optimization in the pharmaceutical sector in veterinary organizations. Data envelopment analysis (DEA), fuzzy data envelopment analysis (FDEA), and sensitivity analysis are used to formulate the problem. The paper investigated the influence of resilience indicators on PSCs. The results of the research show that redundancy is the most influential factor in PSC in a veterinary organization

Table 1.
Contribution of researchers in modeling resilient PSC

(*continued*)

S. N	References	Description
13	Aigbogun *et al.* (2016)	The paper did a comparative study between the vulnerabilities and capabilities of the Malaysian pharmaceutical industry and aimed to develop the framework to enhance the resilience of the pharmaceutical supply chain. The four dimensions of vulnerabilities as turbulence, external pressure, sensitivity and connectivity and six dimensions of capabilities as flexibility, visibility, adaptability, collaborations, reverse capacity and supplier's disparity are reported
14	Lawrence *et al.* (2020)	The paper focuses on finding core causes and other intermediate events that become the reasons for risks and disruptions in the pharmaceutical supply chain in the USA. A Bayesian causality model has been developed to quantify the risk. The quantification is analyzed by using techniques like predictive inference reasoning and sensitivity analysis
15	Fertier *et al.* (2021)	The objective of the paper is to enhance the resilience in the supply chain by using a model and event-driven approach from crisis management. The study accesses the accuracy, cost and speed of new risk identification by evaluating the architecture of the pharmaceutical supply chain and the segregation of different data streams into a single decision-making platform
16	Jorge and González (2016)	The research aims to assess supply chain resilience by considering capacity enablers that help to prepare better for unstable and risky conditions. The model has been proposed based on three indicators: organizational resilience, business resilience and labor resilience by assessing flexibility, responsiveness, days of inventory, days of receivables and days of payables
17	Jerome *et al.* (2021)	The paper identified and studied the intensity of challenges during the pandemic era by using total interpretive structural modeling. The paper commented that collaboration between organizations and networks of suppliers could lead to resilience
18	Lücker *et al.* (2019)	The paper aims to manage risks and disruptions in the supply chain by using inventory and reserve capacity under stochastic demand. The results determine optimal inventory levels and reserve capacity production rates. The study put forward four risk mitigation strategies: inventory strategy, reserve capacity strategy, mixed strategy and passive acceptance. The paper illustrated that mitigation strategy depends on functional characteristics of the product and supply chain agility and efficiency
19	Rewari *et al.* (2020)	The research proposed measures to improve the resilience of the antiretroviral drug supply during the COVID-19 pandemic and prepare for future disruptions
20	Mansor and Kamarulzaman (2020)	The paper aims to identify the origin of risks in the supply chain of seaweed cultivation in Malaysia. Data analysis was done by using failure mode and effect analysis (FMEA). The results show that farmers faced 19 unique risks, while 13 intermediate risks by both parts and 16 risks on the customer's part. The study suggested enhancing the resilience level to tackle the disruptions
21	Tambo *et al.* (2018)	The objective of the study is to fortify sustainable, resilient and innovative programs to eradicate the infectious diseases of poverty
22	Golan *et al.* (2021)	The paper performed a literature survey on modeling supply chain resilience from 2007 to 2020 based on the vaccine manufacturing supply chain. Literature shows that artificial intelligence (AI), stress tests and digital twins can quantify the resilience trade-off with the system's performance after disruptions

(*continued*)

Table 1.

S. N	References	Description
23	Nguyen *et al.* (2021)	The aim is to interrelate supply chain risk, integration, resilience and firm performance. The outcomes of results show that supply chain risk has a negative influence on supply chain integration statistically. However, supply chain integration has a positive impact on supply chain resilience and a firm's performance. The research is based on the Vietnamese pharmaceutical supply chain and hence, recommended supply chain integration as critical criteria to ensure performance and supply chain resilience
24	Mandal (2017)	The findings of the paper illustrate that technological orientation has a positive influence on healthcare resilience. The results show that more focus on developing a competing value framework (CVF) can effectively mitigate the risks and achieve timely healthcare services
25	Sundarakani and Onyia (2021)	The study investigated the financial and operational resilience of supply chain organizations in the UAE. The findings of the study stated that the government's robust financial support to the logistics industry resulted in minimal interruptions during the COVID-19 pandemic
26	Weitzel *et al.* (2021)	The study explored the paradigm shift that affects pharmaceutical quality. It uses an analytical procedure lifecycle approach; enhanced data management techniques and utilization of digital technologies have been identified as the key solutions to achieving the required quality. In addition to that, stakeholder collaborations are required to maintain the quality of pharmaceutical products
27	Terblanche and Niemann (2021)	The paper tried to find out and expand the capabilities of risk mitigations in the supply chain to minimize counterfeiting in the pharmaceutical industry of South Africa by conducting a semi-structured interview with 12 pharmaceutical manufacturers, distributors and retailers. The study stated that counterfeiting could be combated by developing a risk management culture and developing resilience by incorporating flexibility, agility and sensing redundancy
28	Abdolazimi *et al.* (2021)	The study formulated a model to evaluate the influence of the coronavirus pandemic on the healthcare and cold pharmaceutical distribution supply chain. The model tends to minimize the total cost, environmental impacts, lead time and the probability of healthcare provided to the infected person
29	Vanany *et al.* (2021)	The study explored the capabilities of supply chain resilience in response to COVID-19 pandemic disruptions by proposing a double helix framework that includes dimensions of capabilities of resilience and disruptions
30	Tawfik *et al.* (2021)	The article stated that local production of pharmaceuticals could sustain resilience in the healthcare system. In addition to that, the article reviewed the current pharmaceutical production system in Saudi Arabia and proposed remedies to address the major challenges

Table 1.

Figure 1. It shows the framework adopted for the exploration of literature related to resilient PSC. From the extracted articles, research and conference papers focusing on modeling resilient PSC in low-and middle-income countries are filtered. Finally, 65 research and conference papers are selected as most relevant for the study.

3.2 Study design and setting

In addition to the literature review, we conduct a field survey to identify real field issues in the GMSC of India. We chose the New Delhi JAS head office for primary data collection since it is one of the main bodies for generic medicines procurement and distribution across multiple

Search within	Search documents	Results Scopus	WoS	PubMed
All fields	ALL (Pharmaceutical supply chain)	32,067	1,007	3,451
Article title, abstract, keywords	TITLE-ABS-KEY (Supply chain) AND TITLE-ABS-KEY (Resilience)	2,331	905	145
Article title, abstract, keywords	TITLE-ABS-KEY (Pharmaceutical supply chain)	2,376	622	111
All fields	ALL (Pharmaceutical supply chain) AND ALL (Resilience)	1,972	24	26
All fields and Article title, abstract, keywords	ALL (Pharmaceutical supply chain) AND TITLE-ABS-KEY (Resilience)	294	17	16
All fields and Article title, abstract, keywords	TITLE-ABS-KEY (Pharmaceutical supply chain) AND ALL (Resilience)	156	19	3
Article title, abstract, keywords	TITLE-ABS-KEY (Pharmaceutical supply chain) AND TITLE-ABS-KEY (Resilience)	49	13	3

Table 2.
Literature survey results from selected databases

JAS outlets in India. The process of data collection is done in the period from December 2019 to March 2021. Personal visits began in January 2020, but due to the COVID-19 lockdown in India, we switched to telephonic conversations and video conferencing utilizing Google Meet for data collection. We also contact 23 JAS distributors and retail locations in Dehradun, Haridwar and Nainital districts. A total of 44 experts are chosen from the finalized field visit sites, with 27 experts agreeing to participate in the study. Each video and audio conversation lasted approximately 20–30 min. We ask experts to point out key issues in the procurement and delivery of generic medicines. Similarly, we consult experts for suggestions on how to alleviate GMSC vulnerabilities and import resilience. For example, we question retailers whether they have consumer complaints, how long it takes to acquire medicine from the upper levels of the supply chain, what solutions they think will help with existing distribution issues, how COVID-19 has affected their retail locations, and so forth. Finally, all Google Meetings and phone calls are documented, and the information is compiled in Microsoft Excel 16.0.

3.3 Data analysis

We scrutinize each recording prudently and analyze the points of all experts on vulnerabilities and resilience capabilities in Microsoft Excel 16.0. To start, we utilize the strings “issues” and “problems” in Excel’s Find tab to filter out the vulnerabilities. In the same way, “solutions” and “resilience/resilient” strings help us extract data for resilience capabilities. We notice that the majority of the expert comments refer to identical vulnerabilities and resilience capabilities. Because our primary goal is to identify the most critical vulnerabilities and resilience capabilities, we consult with experts in New Delhi to clear up inconsequential vulnerabilities and resilience capabilities. For example, one of the experts points out that mobile applications can be designed and used in JAS for better information sharing among supply chain players as well as for capturing customer feedback; however, New Delhi experts reveal that doing so will require financial support from the government, and it will be difficult to implement in the context of rural India, so we have omitted this solution from the analysis. We choose key vulnerabilities and resilience capabilities from the field survey using the aforementioned procedures. Furthermore, we focused primarily on those publications from the gathered literature in which researchers emphasized vulnerabilities and resilience-related work in the context of India. Finally, based on the literature analysis and expert perspectives, we have identified seven risk-causing vulnerabilities and nine SCRCs, which are detailed in the next section.

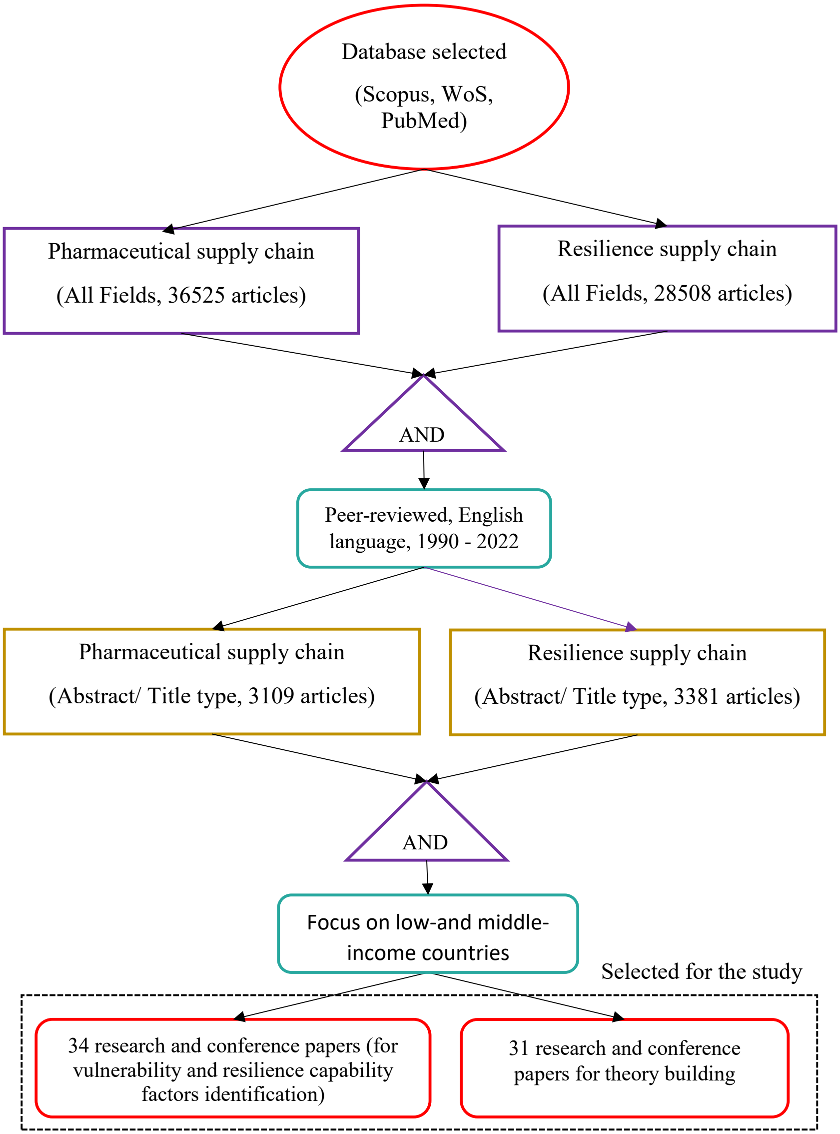

Figure 1.
Literature code tree

4. Vulnerabilities and resilience capabilities in GMSC

4.1 Vulnerabilities

Vulnerabilities are an unpredictable set of actions that can impair the operations of any organization and have a negative impact on the entire system due to natural or unnatural uncertainties. It is measured mathematically in terms of risk assessment by comparing the likelihood of any event and its severity (Soni and Jain, 2011). Since the healthcare system is worst hit by the pandemic, the GMSC of JAS is struggling to provide medicines efficiently and effectively during COVID-19 (Sriyanto *et al.*, 2021). Hence, to understand and evaluate the cause of the poor performance of any organization, first, it is essential to identify the potential vulnerabilities that are creating loopholes in the system, causing the risk to enter and expand. Thus, we discuss seven potential vulnerabilities in Table 3 for GMSC, which can directly or indirectly affect MSMEs supply chain.

4.2 Resilience capabilities

Capabilities are the inbuilt characteristics that a system has and nine key SCRCs are shown in Figure 2 and Table 4 for the GMSC of MSMEs. The goal is to arrange these capabilities according to their significant role in establishing resilience in the system using the hybrid framework. Figure 3 shows vulnerabilities versus capabilities in resilient GMSC.

5. Research framework and analysis

We use a hybrid FDEMATEL-BWM framework shown in Figure 4 to address our research questions. The FDEMATEL is used to find the cause-and-effects vulnerabilities and BWM is

Vulnerabilities	Description	References
Loss of suppliers (V1)	Loss of suppliers is one of the most common threats during a disaster due to the unavailability of raw materials, resources and services	Tang (2006), Pettit *et al.*, (2010), Soni and Jain (2011) and Expert opinion
Breakdown of transportation (V2)	Transportation is the backbone of all types of the supply chain because it connects all the elements of the chain, starting from raw materials to vendors, warehouses, retail stores and finally to the end-users. Transportation breakdown is most common during a disaster. In addition to that, the pandemic situation also requires a partial or complete lockdown of transportation. Hence, this vulnerability also needs special attention during analysis	Pettit *et al.*, (2010), Soni and Jain (2011), Chandra and Kumar (2018a), Shweta (2021) and Expert opinion
Shortages of medicines (V3)	Shortages of medicine are among the most common vulnerabilities of PSC under any circumstances like loss of suppliers, transportation breakdown, internal operational breakdown, or failure	Etemadi *et al.* (2021) and Expert opinion
Loss of human resources (V4)	The disruption causes unavailability of labor, human resources and resources, which leads to delays in the overall supply performance	Pettit *et al.*, (2010), Gonzalez (2016)
Loss of in-hand stock qualities (value) (V5)	Due to disasters and disruptions like floods and pandemics, the in-hand stock or inventory movement gets delayed, resulting in quality deterioration	AbuKhousa *et al.* (2014), Aigbogun *et al.* (2014), Al-Dhaafri and Alosani (2020), Lawrence *et al.* (2020), Shweta *et al.* (2021)
Loss of sales/Revenue (V6)	Loss of sales and revenue is the ultimate threat caused during disruption	Expert opinion
Late deliveries (V7)	The unavailability of human resources, resources, transportation, suppliers and deterioration of quality of stocks result in the late delivery that impacts customer satisfaction. Hence, this is also identified as a vulnerability in GPSC	Lawrence *et al.* (2020), Aigbogun *et al.* (2014) and Expert opinion

Table 3. Vulnerabilities identified in GMSC

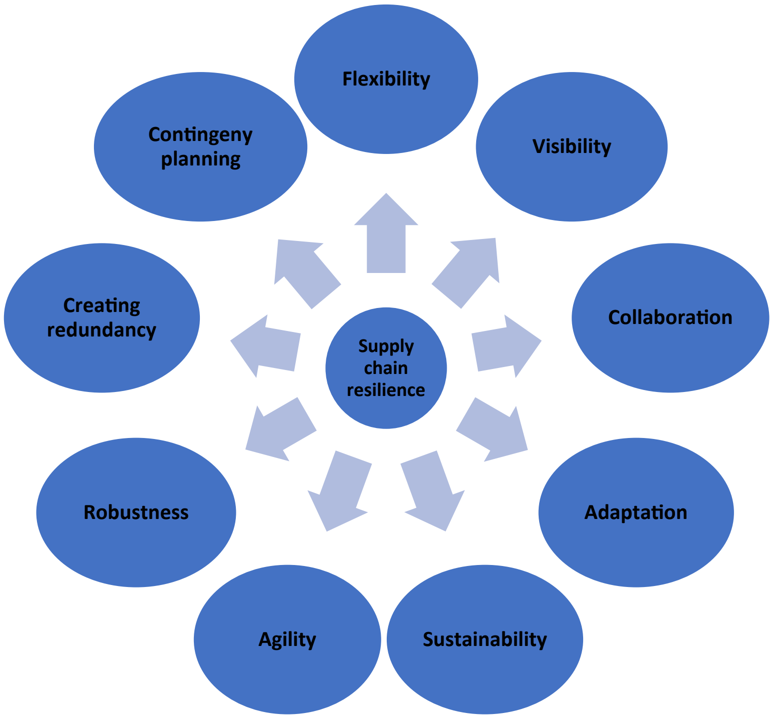

Figure 2.
Supply chain resilience capabilities (SCRCs)

applied to determine the weights of SCRCs. A detailed description of these research methodologies is shown in Appendix 1. In addition, the inputs of various experts through questionnaire survey and conversion of their inputs into final results are also presented in the Tabular form in Appendix 2.

The results of the hybrid framework are given below. First, we discuss the cause-and-effect vulnerabilities and then the resilience capabilities of GMSC.

5.1 Cause-and-effect vulnerabilities

From Table 5, importance indicates the ranking of vulnerability based on their total degree of influence/prominence over each other, whereas, the impact segregates vulnerabilities into cause-and-effect categories (based on positive and negative values). The results can be represented as the follows: Transportation breakdown (V2), loss of human resources (V4) and loss of suppliers (V1) come out as potential cause vulnerabilities that lead to vulnerabilities like shortages of medicines (V3), loss of in-hand stock qualities (V5) and loss of sales/revenue (V6). The late delivery (V7) seems an effect of vulnerability, and it can be considered with less cause-effect as its $R - C$ value is very close to zero; still, it can be concluded as a cause vulnerability that can be the reason for medicine shortages and loss of in-hand qualities. The importance values show the value of the total influence of vulnerabilities, both in terms of receiving and dispatching over each other. The ranking based on the prominence shows the most important barriers that are influencing others in the order as V7 > V2 > V6 > V4 > V1 > V3 > V5. A threshold value α is calculated by equation (A16) is 0.1174, which is the average of the total relation matrix. The values that are greater than threshold value α in the total relation matrix show the significant influence among vulnerabilities, which is highlighted and given in Table 6. Figure 5 shows diagraph plotted between $R_i + C_i$ and

Capabilities	Description	References
Flexibility (CP1)	Flexibility is the ability to mould according to fickle conditions. For an organization, flexibility is the ability to meet the broad expectations of the customer without increasing the cost even under unusual circumstances like disasters and pandemics. This characteristic enhances coordination and gives power to the organization to tackle uncertainties. Therefore, flexibility can be one dimension of achieving a resilient supply chain. This may also help to achieve on-time delivery of goods, monitor capacity utilization and attend to customer requirements quickly. Flexibility can be implemented in the field, like the selection of suppliers, transportation route, lead time, etc.	Pettit *et al.* (2013), Srinivas *et al.* (2013), Katiyar *et al.* (2015), Seetharaman *et al.* (2017)
Visibility (CP2)	Visibility provides characteristics of trackability at each operational point in the supply chain. Visibility can be significant during disruptions as it helps to take a front view so that decision-makers at each level can visualize and identify the causes of disruptions in the supply chain and take corrective countermeasures	Pettit *et al.* (2010, 2013), de Lima *et al.* (2018)
Collaboration (CP3)	Collaboration denotes the degree of teamwork in a supply chain. It is the ability to integrate all the cooperative partners into the unit and frame collaborative planning by coordination of information and knowledge sharing at the individual level so that quick recovery actions can be taken during disruptions. Hence, incorporating a high level of collaboration in the supply chain can more efficiently cope with threats and risk factors. Quality of delivered products and efficiency of suppliers need a collaborative effort to improve the overall performance of the supply chain as any shortcomings on the supplier's side can impact to demand side	Katiyar *et al.* (2015), Schilder (2015), Ali *et al.* (2017), Christopher and Peck (2004), de Lima *et al.* (2018), Awan *et al.* (2013), Chandra and Kumar (2018b)
Adaptation (CP4)	Adaptation is the quality to accept and incorporate the necessary changes required in response to challenging circumstances. It includes quick rerouting, lead time reduction, updating alternate technology, learning and creating a new knowledge database based on experience to deal with disruptions	Mandal (2017), Salehi *et al.* (2020), Chowdhury *et al.* (2021), Golan *et al.* (2021)
Sustainability (CP5)	Sustainability is the term that blends social, economic and environmental perspectives which have been derived from stakeholders' and customers' requirements	Ageron *et al.* (2012), Chandra and Kumar (2020), Zavala-Alcívar *et al.* (2020), Mathiyazhagan *et al.* (2021), Cheng *et al.* (2021), Golroudbary *et al.* (2019), Usman *et al.* (2022)

(*continued*)

Table 4.
SCRCs in GMSC

Capabilities	Description	References
Agility (CP6)	Agility denotes a quick response to change that is required to decrease the impact of disruptions. Hence, agility acts as a capability and supports the system to enhance its flexibility and deliverability of the system. The response of the supply chain can be increased by the reduction of order fulfillment lead time	Ali *et al.* (2017), Katiyar *et al.* (2015), Yusuf *et al.* (1999), Hohenstein *et al.* (2015), Morini (2015)
Robustness (CP7)	It is the ability to withstand adverse conditions and is characterized by providing support during the sudden impact of disruptions. The research shows that robustness fosters supply resilience by acting proactively during potential disruptions	Hohenstein *et al.* (2015), Schilder (2015), Brandon-Jones *et al.* (2014)
Creating redundancy (CP8)	This strategy generates duplicate resources and services at each level. The additional capacity can be created for manufacturers, suppliers, transporters, inventory and warehousing so that it can be utilized immediately during unexpected and uncertain disruptions. This can provide extra time to think about effective solutions. A turbulent environment requires extra resources and stock levels to overcome the turmoil impacted on the supply chain. Redundancy can provide agility as customer orders can be fulfilled quickly using available stock, and hence it helps to reduce the lead time and ultimately enhance customer satisfaction	Christopher and Peck (2004), Morini (2015), Kamalahmadi and Mellat-Parast (2016)
Contingency planning (CP9)	The contingency plan is designed in parallel to the usual plan of an organization. This plan comes into action when there is an instant need. Hence, it is not a full-time operational plan. It acts like a backup strategy to tackle risk and disruptions	Kamalahmadi and Mellat-Parast (2016), Mandal (2017), Seetharaman *et al.* (2017), Pettit *et al.* (2010, 2013), Brandon-Jones *et al.* (2014)

Table 4.

$R_i - C_i$ that is used to visualize cause and effect vulnerabilities simultaneously. Adjacency matrix is made by eliminating significant influence value with 1 and insignificant value with 0 in Table 7 (Wieland and Durach, 2021) that is used to simplify the visualization of interrelationship among all vulnerabilities as shown in Figure 6 (shows influential interrelationship diagram) (Abdullah *et al.*, 2020). Figure 6 shows a significant mutual interrelationship between V3 V7, V2 V7 and V2 V4 that means that late delivery is mutually influenced by shortages in medicines and transportation breakdown whereas loss of human resources is mutually influenced by transportation breakdown.

5.2 Ranking of SCRCs

The results show that the sustainability of an organization bears maximum weightage for achieving resilience that is followed by flexibility, agility and visibility. The weightage

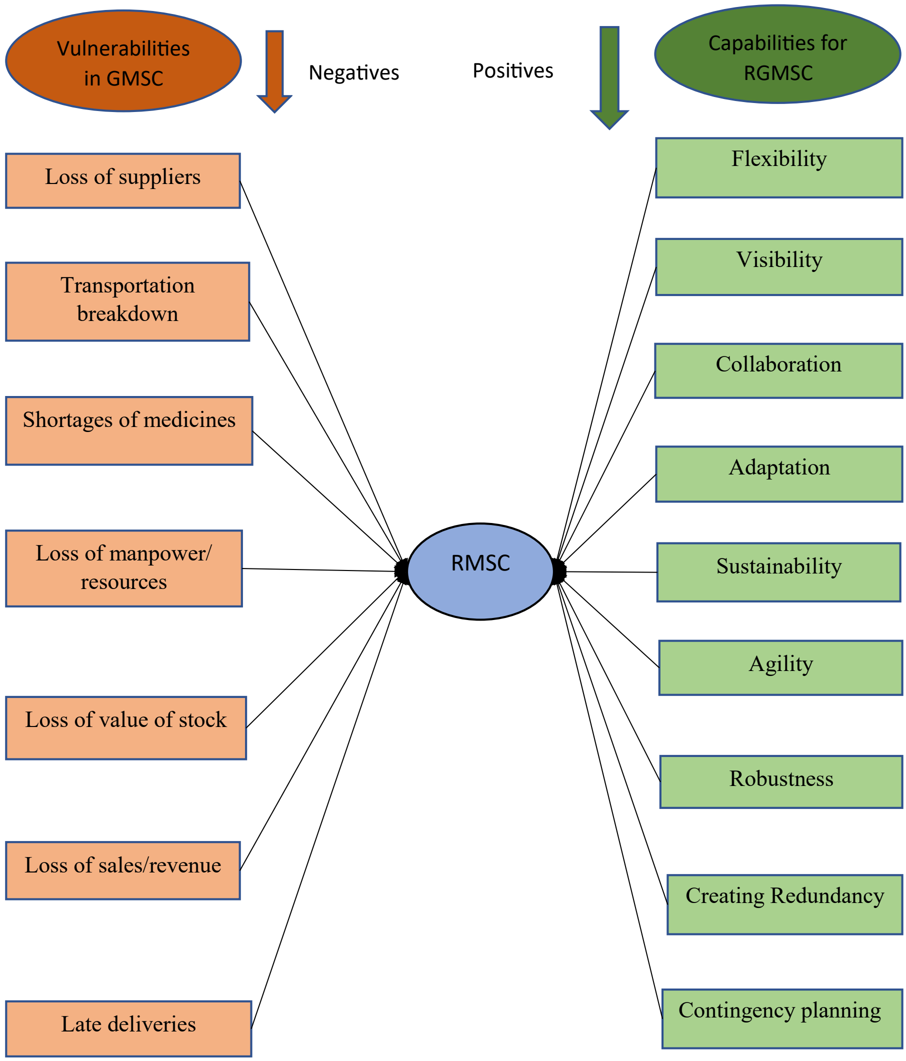

Figure 3.
Vulnerabilities verses resilience capabilities in GMSC

ranked the capabilities as follows: CP5 > CP1 > CP6 > CP2 > CP7 > CP3 > CP4 > CP9 > CP8 (shown in Table 8).

6. Discussion

Resilience thinking has emerged as an inevitable part of the supply chain in any organization. The opportunities for integration of resilience in the PSC can play an important role in MSME's success. During disasters, disruptions and uncertainties, MSMEs suffer the most, thus MSMEs must be given special attention for their future success. In this study, we design a hybrid framework to build resilience in the GMSC of MSMEs that can help to mitigate the risk caused by various disruptions. We propose four research questions and unfold each

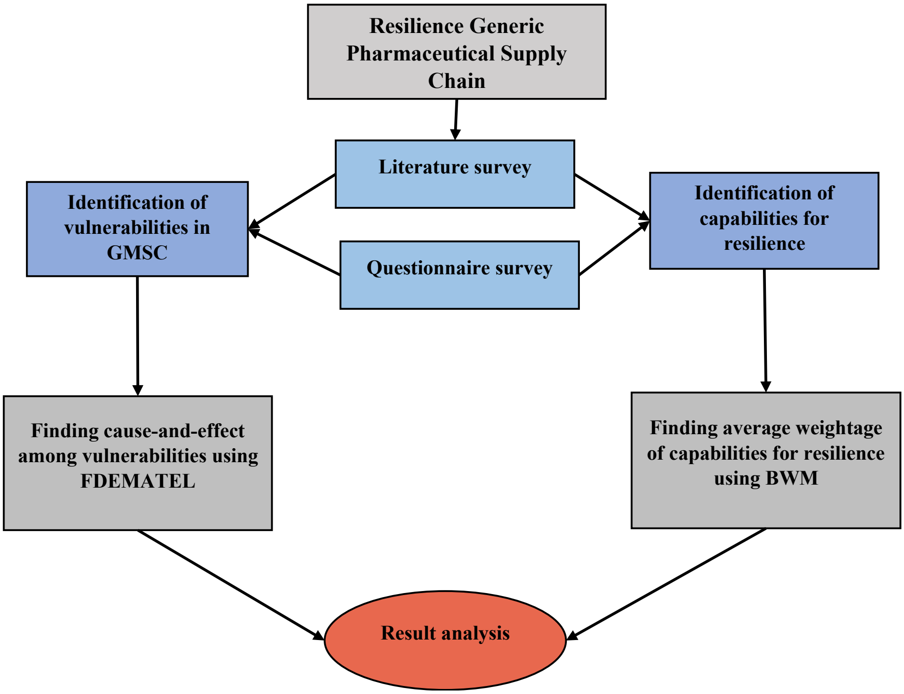

Figure 4.
Research framework

Table 5.
Cause-and-effect vulnerabilities in GMSC

V	R_i	C_i	$R_i + C_i$	Importance	$R_i - C_i$	Impact	Category
V1	0.98435	0.57111	1.55546	5	0.41324	3	Cause
V2	1.28359	0.55809	1.84168	2	0.72549	1	Cause
V3	0.59405	0.94803	1.54207	6	−0.354	5	Effect
V4	1.15619	0.45518	1.61137	4	0.70101	2	Cause
V5	0.42802	0.9849	1.41292	7	−0.5569	6	Effect
V6	0.33824	1.33818	1.67642	3	−0.9999	7	Effect
V7	0.9673	0.89624	1.86353	1	0.07106	4	Cause

Table 6.
Significant influence among vulnerabilities ($\alpha = 0.1174$)

	V1	V2	V3	V4	V5	V6	V7
V1	0.056	0.115	*0.160*	0.106	*0.155*	*0.219*	*0.173*
V2	*0.192*	0.065	*0.250*	*0.150*	*0.222*	*0.220*	*0.185*
V3	0.036	0.038	0.044	0.029	0.066	*0.214*	*0.167*
V4	*0.128*	*0.156*	*0.194*	0.053	*0.184*	*0.233*	*0.208*
V5	0.029	0.025	0.073	0.027	0.038	*0.179*	0.057
V6	0.048	0.027	0.037	0.046	0.098	0.045	0.038
V7	0.083	*0.132*	*0.190*	0.044	*0.222*	*0.227*	0.069

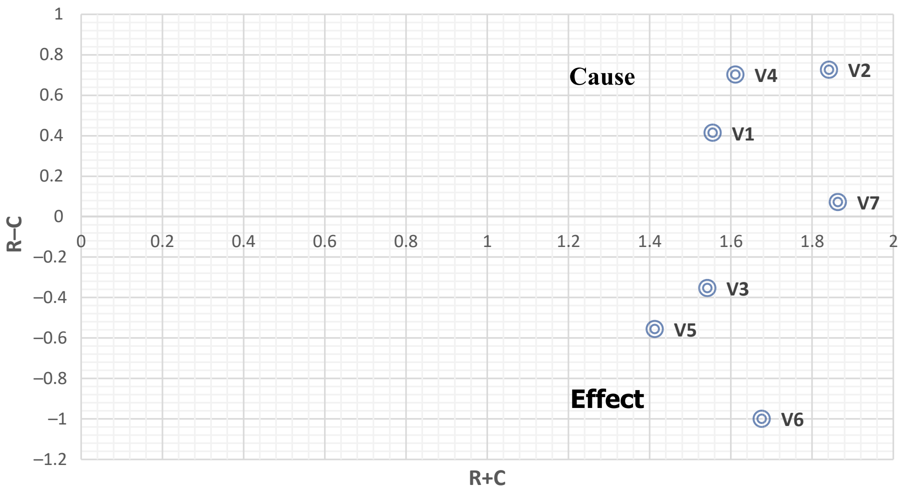

Figure 5.
Cause and effect diagram

	V1	V2	V3	V4	V5	V6	V7
V1	0	0	*1*	0	*1*	*1*	*1*
V2	*1*	0	*1*	*1*	*1*	*1*	*1*
V3	0	0	0	0	0	*1*	*1*
V4	*1*	*1*	*1*	0	*1*	*1*	*1*
V5	0	0	0	0	0	*1*	0
V6	0	0	0	0	0	0	0
V7	0	*1*	*1*	0	*1*	*1*	0

Table 7.
Adjacency matrix

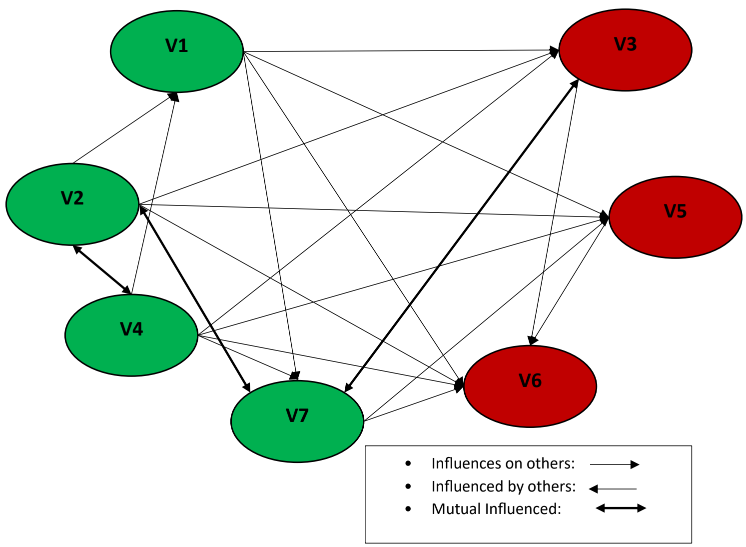

Figure 6.
Influence interrelationship diagram

CP	AVG WT.	Ranking
CP1	0.13953	2
CP2	0.127859	4
CP3	0.102002	6
CP4	0.100787	7
CP5	0.160914	1
CP6	0.130952	3
CP7	0.113976	5
CP8	0.051967	9
CP9	0.072014	8

Table 8.
Ranking of SCRCs

through our hybrid framework. RQ1 is answered through the identification of seven risk-causing vulnerabilities in GMSC of MSMEs. Of the seven vulnerabilities, late deliveries (V7) is the most important vulnerability for the decision-makers to improve their performance. In an emergency such as an outbreak, a medicine, if reached on time to the desired location can help in saving a human life. The second COVID-19 wave that hit India in April 2021 showed the importance of the on-time delivery of oxygen cylinders in various hospitals in India. Today, many generic medicines help in treating and saving individuals from various diseases, for instance, hypertension. Hypertension may lead to heart attack, and the role of on-time delivery and consumption of generic medicine metoprolol (a hypertension medicine) is very crucial for its patient. Thus, decision-makers should try to minimize the late deliveries in the supply chain so that medicines reach on time to the patients. In many developed countries, pharmaceutical companies and healthcare organizations use 3PLs or Drones to deliver medicines during emergencies. The policy-makers of JAS can experiment with the aforementioned delivery options on a smaller scale in India, and if the results are positive, they can be implemented in other states of India.

For RQ2, we segregated the vulnerabilities into the cause-and-effect categories that can help to identify the driving and dependent vulnerabilities. For that purpose, we derive the importance and impact of vulnerabilities and show that factors such as transportation breakdown (V2) are the cause/driving factor that leads to issues or vulnerabilities such as loss of in-hand stock qualities (V5) and loss of sales/revenue (V6). Government-operated healthcare organizations in India often face challenges to manage the PSC because they do not have the proper technological infrastructure and decision-making techniques to manage their transportation activities. Private sectors pay a good amount to optimization consultants to identify issues and improve their transportation performance, however, such practice is not seen in the government agencies. Nowadays, much focus is being given in healthcare industries to optimizing transportation problems as it is considered the backbone of PSC. Various mathematical models are being proposed by the researchers to improve transportation performance in the context of PSC of private agencies in India. We expect more such studies to come in the future to help government agencies to manage their transportation issues.

Ranking resilience capabilities for GMSC help us answer RQ3. We identify nine SCRCs to mitigate risk during disruption. We show that sustainability (CP5) followed by flexibility (CP1), and agility (CP6) are three important SCRC to mitigate risk and improve system performance. Today, sustainability is being promoted and practiced in many organizations globally, however, Indian healthcare organizations still face many barriers to implementing sustainability concepts in their supply chain and other activities. Various studies have demonstrated a positive link between a sustainable healthcare system and customer satisfaction. If implemented, the same can benefit the GMSC of MSMEs in India. Other factors such as flexibility and agility are essential in GMSC to manage demand and supply uncertainty. Finally, RQ4 is answered by proposing a framework for an integrated RGMSC strategy based on the results of the study shown in Figure 7. We identify visibility in the supply chain as one of the prime capabilities of a resilient supply chain. Hence, the framework provides provision for quick recovery action that could be possible if we improve the visibility among each element of the supply chain by implementing data sharing policies and using the latest technologies of industry 4.0, IoT and smart contract that is an application of blockchain technology. During sudden disruptions, transportation breakdown, loss of manpower/resources and loss of suppliers are the main vulnerabilities that are leading to a shortage of medicines, late delivery and ultimately loss of value of the stock. To deal with such situations, backup redundant resources at the stage of suppliers, warehouses and transportation are needed. In addition to that, a contingency plan must be ready so that company can react suddenly after the impact of disruptions. In the end, the framework entails that there is a need for knowledge updating, adaptability, agility, system robustness and sustainability after overcoming the uncertainties so that, it can handle the future disruptions more effectively.

The selected companies in our study deal with more than 500 suppliers and 5,000 retail stores from all over the country, any disruptions due to pandemics or other disasters would impact the MSMEs. Therefore, we develop an additional framework that focuses on RGMSC. In this scenario, the well-designed mitigation strategies for risk and threat if modeled can save the affected MSMEs. Integration of resilience in GMSC may help enhance the visibility and flexibility of the supply process that is the system may be useful to fulfill the demands even during disruptions. The collaborative approach encourages team effort to help in the data sharing, updating knowledge through the digitization process for future references. Creating redundancy contingency planning will promote emergency sourcing, multiple and diversified suppliers and transportation partners. Quick adaptability toward fickle

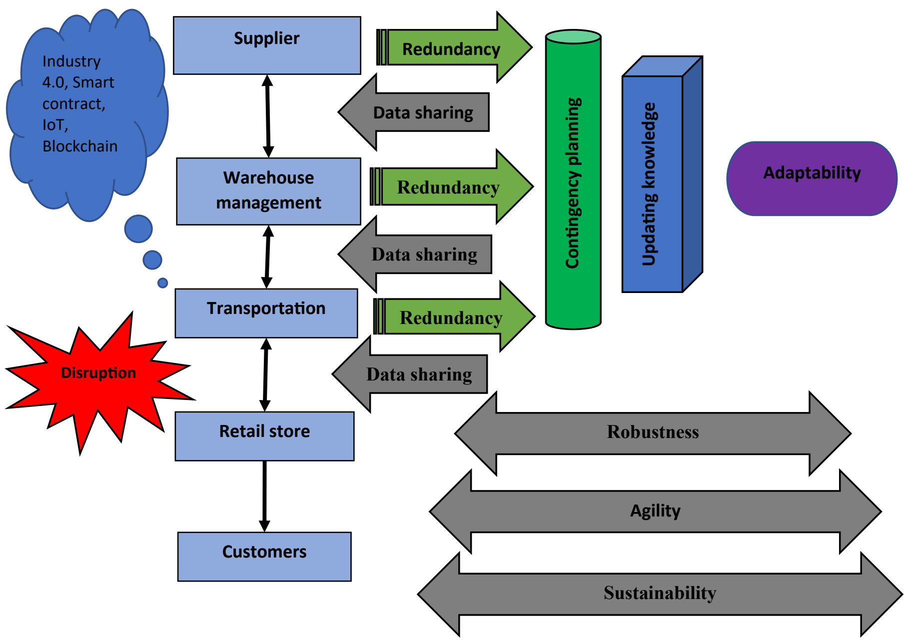

Figure 7. Framework for resilient GMSC

circumstances also needs to be implemented to bring down the magnitude of disturbance. In the end, agility, robustness and sustainability needed to be incorporated into the system as an inevitable part. The framework developed for a resilient supply chain in GMSC is shown in Figure 7.

6.1 Managerial implications

Our study has implications for the policy-makers of JAS, GoI. First, the identification of important risk-causing vulnerabilities and their causal analysis can be useful for policy-makers to optimize their resources and focus on key vulnerabilities, which are the main causes of risk in GMSC. Minimizing the transportation breakdown and loss of human resources can assist MSMEs to improve supply chain efficiency and effectiveness to maximize generic medicine coverage in India. We also propose key resilient capabilities to mitigate risk in GMSC. Formulating a strategic plan and implementing the proposed resilient capabilities can help MSMEs to prepare for global disruptions like COVID-19 in the future. Though implementing SCRCs in existing MSMEs is a challenging task due to funding issues, however, if third-party organizations, for instance, GAVI and UNICEF come forward in such emergencies, gradually it may help to improve the performance of the healthcare system in India. Collaborations, one of our SCRCs can indeed be a great solution for JAS to manage the vulnerabilities of GMSC. A third party can provide policy-makers with optimal solutions to abate vulnerabilities, the primary source of risk. Performance improvement can further act as a catalyst to import sustainability in JAS of MSMEs. Various healthcare organizations have shown a positive relationship between supply chain performance improvement and substantiality development. Thus, in the current COVID-19 situation, the policy-makers of JAS need to mitigate the risks in the supply chain so that generic medicines reach on time with optimum consumption of resources. To do so, our study has prioritized the SCRCs that can mitigate risk and help to ingress sustainability in the JAS MSMEs.

6.2 Comparative study

This study aimed to find out the prominence of vulnerabilities caused during disruptions in MSME PSC operated under JAS scheme of GoI. The results of FDEMATEL shows that loss of human resources, loss of suppliers and transportation breakdown are the most significant causes that lead to other vulnerabilities like shortages of medicines, loss of in-hand stock quality and loss of sales/revenue that ultimately results into late delivery. Various study in literature reported, loss of suppliers and transportation penalty cost as prime risk in PSC during disaster and disruptions. In addition to that, wasting of medical resources and lack of planning for the sudden disruptions are the main determinant of vulnerabilities in PSC (Mehralian *et al.*, 2015; Wang *et al.*, 2017; Bastani *et al.*, 2021a, b) Wastage of resources and lack of planning could be deal by designing contingency planning.

On the other hand, supply chain resilience capabilities are ranked using BWM so as to develop resilient PSC framework. The results of BWM show that sustainability, visibility and flexibility are the potential capability used to establish resilience in supply chain. To integrate resilience in supply chain, many literature reported that visibility with hassle free information flow, flexibility and collaborative efforts and multiple sourcing, i.e. redundancy are the most influential performance indicators mentioned in literature (Karmaker and Ahmed, 2020; Rehman and Ali, 2022).

7. Conclusion, limitations and future scope

COVID-19 pandemic caused disruptions in every sector, including automobile and healthcare, that directly or indirectly impacted MSMEs. Being one of the largest generic drug suppliers and a diversified country, there is an urgent need in India to establish sustainability and resilience in the generic medicine supply chain of MSMEs. This study selected an Indian public sector generic medicine distribution company that is implementing the agency of the JAS for the establishment of resilience in the supply chain. Then, a hybrid framework using FDEMATEL-BMW is proposed, first, to find out the cause-and-effect vulnerabilities in GMSC (during the advent of uncertain situations), and second, to rank the capabilities of the resilient supply chain so that an optimal strategy can be proposed to establish a resilient generic medicine supply chain. The outcome of this study can help the decision-makers to optimize the GMSC of MSMEs. The study has benefits for the GMSC in India, however, it is not free with some limitations. First, the vulnerability and resilience capabilities are identified from the literature and expert's opinions, thus few important parameters for mitigating risk and designing resilient GMSC may have been overlooked. Secondly, the results are primarily based on a hybrid framework premeditated with MCDM techniques, which has limitations to produce global optimal results. Consequently, the identification of cause-and-effect vulnerabilities and resilience prioritization obtained in this study may vary in the case of GMSC of other developing nations. The present work can be extended in the future to compare the results with other MCDM techniques, which can help to validate the present findings.

To summarize, we identify critical vulnerabilities in GMSC and provide mitigation strategies in the form of resilience capabilities. As a result, our findings have several implications for future research. For instance, we illustrate that a shortage of medicines is a significant vulnerability and these shortages can be caused by various factors such as poor forecasting, inopportune inventory management and unskilled health workers. Thus, designing predictive forecasting tools using AI, applications of blockchain in GMSC, training and education of health workers through digital technology, and maximum coverage location problems to order medicines from nearby warehouses and maximize the targeted population in case of emergency are a few domains where research gaps exist and can be well addressed in future in GMSC. Other vulnerabilities such as loss of suppliers can be a potential area of research using optimal supplier selection and order allocation problems and vendor relationship management. Sustainability in GMSC is proposed as an important resilience capability in our study. Thus, sustainable development may help to mitigate vulnerabilities in GMSC. Recently, supply chain coordination (SCC) has attracted researchers in healthcare (Chandra and Vipin, 2021). SCC using procurement supply contracts such as buyback, payback, revenue sharing, on-time delivery and options contracts can significantly improve the GMSC performance, and thus aforementioned contracts can be considered in the GMSC future research.

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Appendix 1
Description of FDEMATEL and BWM methodologies.

A.1. Fuzzy set theory

A fuzzy set is a class of objects which denotes uncertainty. The value of uncertainty is characterized by the help of the membership function with the help of range zero to one (Zadeh, 1965). The fuzzy set provides a framework for understanding the concept of vague and rigorous situations mathematically. Generally, triangular fuzzy numbers (TFNs) are simple and efficient in computation and describe fuzzy information sufficiently (Shweta and Kumar, 2020). Therefore, TFNs as the membership functions have been selected with the DEMATEL approach. The representation of TFNs is shown in Figure A1. The membership function μ (*x*) and the triangular fuzzy numbers have been developed by (Zadeh, 1965) shown below.

$$\mu(x) = \begin{cases} \dfrac{x-l}{m-l}, x \in [l, m] \\ \dfrac{x-u}{m-u}, x \in [m, u] \\ 0, \text{ otherwise} \end{cases}$$

To defuzzify the TFN, the graded mean integration representation (GMIR) (Kumar *et al.*, 2021) is used, which is formulated as follows:

$$G(M_i) = \frac{l_i + 4m_i + u_i}{6}$$

A.2. FDEMATEL

The DEMATEL approach was first proposed by the Battelle Memorial Institute Geneva Research Centre (Gabus and Fontela, 1972). DEMATEL is the technique to analyze the interrelations and find out the influence and impact of identified factors by separating them into cause-and-effect categories. DEMATEL was further integrated with fuzzy theory to incorporate vagueness and ambiguities while making decisions. The steps followed in this study are given below:

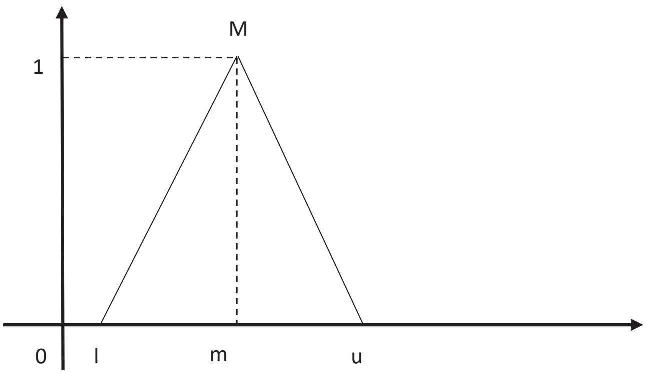

Figure A1. Triangular fuzzy number

Step 1: Fuzzy initial direct relation matrix

The experts are provided a questionnaire based on the Likert scale to access the impact of the vulnerability of ith factor on jth factor and converted in the fuzzy form based on Table 3. The judgment of each expert is taken in a distinct fuzzy matrix $\widetilde{B}_{ijk}$ (shown in equation A1).

$$\widetilde{B}_{ijk} = \left(\widetilde{b}_{ijk}\right)_{n \times n} = \begin{vmatrix} 0 & \widetilde{b}_{12k} & \widetilde{b}_{1nk} \\ \widetilde{b}_{21k} & 0 & \widetilde{b}_{2nk} \\ . & & . \\ . & & . \\ . & & . \\ \widetilde{b}_{n1k} & \widetilde{b}_{n2k} & 0 \end{vmatrix} \tag{A1}$$

where, $\widetilde{b}_{ijk} = (l_{ijk,}\ m_{ijk},\ u_{ijk})$ i and j show pairwise values of each element, and k denotes the number of respondents.

Now, all K fuzzy matrices are aggregated into a single matrix $\widetilde{Y}$ to obtain a fuzzy initial direct relation matrix.

$$\widetilde{Y} = \begin{vmatrix} 0 & \widetilde{y}_{12} & \widetilde{y}_{1n} \\ \widetilde{y}_{21} & 0 & \widetilde{y}_{2n} \\ . & & . \\ . & & . \\ . & & . \\ \widetilde{y}_{n1} & \widetilde{y}_{n2} & 0 \end{vmatrix} \tag{A2}$$

$$\widetilde{y}_{ij} = (l_{ij,}\ m_{ij},\ u_{ij}) = \left[\min(l_{ijk}),\ \frac{1}{k}\,\Sigma_k \max(u_{ijk})\right] \ldots\ldots \text{where, } (k = 1,\ 2 \ldots\ldots\ldots\ldots\ldots K) \tag{A3}$$

Step 2: Normalized Fuzzy matrix

The normalized fuzzy direct matrix $\widetilde{Q}$ is developed employing equations (A5) and (A6)

$$\widetilde{Q} = \begin{vmatrix} \widetilde{q}_{11} & \widetilde{q}_{12} & \widetilde{q}_{1n} \\ \widetilde{q}_{21} & \widetilde{q}_{22} & \widetilde{q}_{2n} \\ . & & . \\ . & & . \\ . & & . \\ \widetilde{q}_{n1} & \widetilde{q}_{n2} & \widetilde{q}_{33} \end{vmatrix} \tag{A4}$$

where,

$$\tilde{Q} = (\tilde{q}_{ij}) = \frac{\tilde{y}_{ij}}{r} = \frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r} \tag{A5}$$

$$r = \max\left(\max_{1\le i\le n}\left(\Sigma_{j=1}^{n} u_{ij}\right) \max_{1\le j\le n}\left(\Sigma_{i=1}^{n} u_{ij}\right)\right) \tag{A6}$$

Step 3: Total Fuzzy relation matrix

Total Fuzzy relation matrix $\tilde{T}$ is estimated by adding all direct and indirect effects of factors by equation (A7),

$$\tilde{T} = \lim_{k\to\infty}\left(\tilde{Q}^1 + \tilde{Q}^2 + \ldots\ldots\tilde{Q}^k\right) = \tilde{Q} \times \left(I - \tilde{Q}\right)^{-1} \tag{A7}$$

As $\tilde{Q}$ is a fuzzy matrix, to ease out the difficulty of calculation, the crisp matrices Q_l Q_m and Q_u were formed from $\tilde{Q} = (\tilde{q}_{ij}) = (l'_{ij,}\ m'_{ij},\ u'_{ij})$, where l', m' and u' are the lower, middle and upper elements of the normalized fuzzy matrix $\tilde{N}$ (Gabus and Fontela, 1972).

$$Q_l = \begin{vmatrix} 0 & l'_{12}\ldots\ldots\ldots & l'_{1n} \\ l'_{21} & 0\ldots.. & l'_{2n} \\ . & & . \\ . & & . \\ . & & . \\ l'_{n1} & l'_{n2\ldots\ldots} & 0 \end{vmatrix} \tag{A8}$$

$$Q_m = \begin{vmatrix} 0 & m'_{12}\ldots\ldots\ldots & m'_{1n} \\ m'_{21} & 0\ldots.. & m'_{2n} \\ . & & . \\ . & & . \\ . & & . \\ m'_{n1} & m'_{n2\ldots\ldots} & 0 \end{vmatrix} \tag{A9}$$

$$Q_u = \begin{vmatrix} 0 & u'_{12}\ldots\ldots\ldots & u'_{1n} \\ u'_{21} & 0\ldots.. & u'_{2n} \\ . & & . \\ . & & . \\ . & & . \\ u'_{n1} & u'_{n2\ldots\ldots} & 0 \end{vmatrix} \tag{A10}$$

After constructing three matrices Q_l Q_m andQ_u, the total fuzzy relation matrix $\widetilde{T}$ for this study is calculated by equation (A7)

$$\left[l_{ij}^{''}\right] = Q_l \times (I - Q_l)^{-1};\ \left[m_{ij}^{''}\right] = Q_m \times (I - Q_m)^{-1};\ \left[u_{ij}^{''}\right] = Q_u \times (I - Q_u)^{-1} \tag{A11}$$

where $(l_{ij}^{''}, m_{ij}^{''}, u_{ij}^{''}) = \widetilde{t}_{ij}$ are the fuzzy elements of $\widetilde{T}$

$$\widetilde{T} = \widetilde{t}_{ij} = \begin{vmatrix} \widetilde{t}_{11} & \widetilde{t}_{11}\ldots\ldots\ldots & \widetilde{t}_{1n} \\ \widetilde{t}_{21} & \widetilde{t}_{22}\ldots\ldots & \widetilde{t}_{2n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \widetilde{t}_{n1} & \widetilde{t}_{n2}\ldots\ldots & \widetilde{t}_{nn} \end{vmatrix} \tag{A12}$$

Step 4: Defuzzification of total fuzzy relation matrix

After calculating the total fuzzy matrix $\widetilde{T}$ by equations (A7)–(A12), we defuzzify $\widetilde{T}$ by using equation (A15) to obtain a crisp total relation matrix $T = (t_{ij})$

$$(t_{ij}) = \frac{l_{ij}^{''} + 4m_{ij}^{''} + u_{ij}^{''}}{6} \tag{A13}$$

Step 5: Calculating prominence (R + C) and relation (R–C)

$$R = \left[\sum_{j=1}^{n} t_{ij}\right]_{n*1} \tag{A14}$$

$$C = \left[\sum_{i=1}^{n} t_{ij}\right]_{1*n} \tag{A15}$$

The value of $(R + C)$ specifies the influence of each factor, whereas $(R - C)$ values split the factors into cause-and-effect groups.

Step 6: Cause and effect diagram

The positive value of $(R - C)$ denotes the "cause" category while the negative value of $(R - C)$ depicts the "effect" group. By plotting $(R - C)$ and $(R + C)$ values on vertical and horizontal axes, respectively, the cause-and-effect digraph developed.

Step 7: Interrelationship diagram

Threshold value α is calculated by taking the average value of all the factors in the total relationship matrix. The factors having influence more than α are identified, and an interrelationship diagram is established.

Linguistic variables	TFN
No influence (NO)	(0.0, 0.0, 0.25)
Very low influence (VL)	(0.0, 0.25, 0.5)
Low influence (L)	(0.25, 0.5, 0.75)
High influence (H)	(0.5, 0.75, 0.1)
Very high influence (VH)	(0.75, 1, 1)

Source(s): Chirra and Kumar (2018)

Table A1. Linguistic variables to Triangular fuzzy number conversion

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}(t_{ij})}{N} \tag{A16}$$

A.3. BWM

The best-worst method is one of the recently evolved to solve the MCDM problems that have been developed by Rezaei (2015). The concept of BWM is based on a comparison of multi-criteria identified concerning best and worst criteria perceptions by experts. Hence, the methodology conducts the pairwise comparison of all the criteria with best-chosen criteria and worst chosen criteria. During the pairwise comparison of criteria with best criteria, the best attributes selected are scaled as 1, and the remaining attributes are scaled according to the best reference. Similarly, during the pairwise comparison of all the attributes with the worst attribute, the worst attribute selected is scaled as 1, and the remaining are scaled according to reference worst. The analysis is being initiated by performing an online questionnaire survey that constitutes a pairwise comparison among all selected capabilities. Steps in the BWM are as follows:

Step 1: Find out the set of attributes used for decision-making. Assume the set of attributes as $\{a_1, a_2, a_3, \ldots\ldots a_n\}$.

Step 2: Identify the most desirable, i.e. best attribute, and least desirable, i.e. worst attributes among the set of attributes. In this step, the best and worst attributes are selected by the experts or decision-makers.

Step 3: The one that has been selected as best is scaled as 1, and all other attributes are ranked concerning best so that the least good among all would be 9 on a 1 to 9 scale. The result of this step is the vector of best to other (BO) that would be $X_B = (x_{B1}, x_{B2}, \ldots., x_{Bn})$ where x_{Bj} shows the preference of best attribute B over attribute j, and it is deduced to $x_{BB} = 1$.

Step4: Similarly, for the worst attribute, 1 is assigned, and all other attributes are assigned according to preference, with the rest to worst on a 1 to 9 scale. The result of this step is the vector of others to worst (OW), which would be $X_W = (x_{1W}, x_{2W}, \ldots., x_{Wn})$, where x_{jW} shows the preference of worst attribute W over attribute j, and it is deduced to $x_{WW} = 1$.

Step 5: The next step is to find optimal weights $(w_1^*, w_2^*, \ldots\ldots, w_n^*)$. The optimal weights of the attribute will satisfy the requirements as follows:

For each pair of $w_B/w_j$and w_j/w_W, the values are $\frac{w_B}{w_j} = x_{Bj}$ and $\frac{w_j}{w_W} = x_{jW}$. Hence, to get an optimal solution, minimization of maximum absolute distance, i.e. $\left|\frac{w_B}{w_j} - x_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - x_{jW}\right|$ for all j is required. Considering non-negative and sum conditions for the weights, the problem is resulted as,

$$\min \max_j \left\{ \left|\frac{w_B}{w_j} - x_{Bj}\right|, \left|\frac{w_j}{w_W} - x_{jW}\right| \right\}$$

Subjected to

$$\sum_j w_j = 1 \qquad w_j \geq 0 \text{ for all } j \tag{A17}$$

the above problem can be linearized as min ζ^L.

Subjected to,

$$\begin{gathered} |w_B - x_{Bj}w_j| \leq \zeta L \text{ for all } j \\ |w_j - x_{jW}w_W| \leq \zeta L \text{ for all } j \\ \sum_j w_j = 1 \\ w_j \geq 0 \text{ for all j} \end{gathered} \tag{A18}$$

on solving the above converted linear equation, the optimal weights $(w_1^*, w_2^*, \ldots\ldots, w_n^*)$ and ζ^{L*} are obtained, where the value of ζ^{L*} shows consistency of the system in which the value closer to zero act as more consistent.

Appendix

2. Fuzzy DEMATEL and BWM preliminary results based on experts' inputs through the questionnaire

	V1			V2			V3			V4			V5			V6			V7		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
V1	0	0	0	0	0.25	0.5	0.75	1	1	0	0	0.25	0	0.25	0.5	0.25	0.5	0.75	0.25	0.5	0.75
V2	0.75	1	1	0	0	0	0.75	1	1	0.25	0.5	0.75	0.5	0.75	1	0.5	0.75	1	0.75	1	1
V3	0	0	0.25	0	0	0.25	0	0	0	0	0	0.25	0	0	0.25	0.75	1	1	0.5	0.75	1
V4	0	0	0.25	0.25	0.5	0.75	0.25	0.5	0.75	0	0	0	0.25	0.5	0.75	0.25	0.5	0.75	0.5	0.75	1
V5	0	0	0.25	0	0	0.25	0	0	0.25	0	0	0.25	0	0	0	0.75	1	1	0	0	0.25
V6	0	0	0.25	0	0	0.25	0	0	0.25	0	0	0.25	0	0	0.25	0	0	0	0	0	0.25
V7	0	0.25	0.5	0.5	0.75	1	0.75	1	1	0	0	0.25	0.75	1	1	0.5	0.75	1	0	0	0

Table A2.
Fuzzy initial direct relation matrix

Table A3.
Normalized fuzzy matrix

	V1			V2			V3			V4			V5			V6			V7		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
V1	0	0	0	0	0.069	0.125	0	0.083	0.167	0	0.056	0.167	0	0.069	0.125	0.042	0.11111	0.16667	0.04167	0.09722	0.16667
V2	0.083	0.146	0.167	0	0	0	0.125	0.167	0.167	0.042	0.104	0.167	0.083	0.125	0.167	0	0.0625	0.16667	0	0.08333	0.16667
V3	0	0	0.042	0	0	0.042	0	0	0	0	0	0.042	0	0	0.042	0.125	0.16667	0.16667	0.08333	0.14583	0.16667
V4	0	0.063	0.167	0.042	0.104	0.167	0.042	0.104	0.167	0	0	0	0.042	0.083	0.125	0.042	0.10417	0.16667	0.08333	0.125	0.16667
V5	0	0	0.042	0	0	0.042	0	0.042	0.125	0	0	0.042	0	0	0	0.083	0.14583	0.16667	0	0.02083	0.08333
V6	0	0.021	0.083	0	0	0.042	0	0	0.042	0	0.021	0.083	0	0.063	0.167	0	0	0	0	0	0.04167
V7	0	0.042	0.083	0.042	0.125	0.083	0.063	0.167	0.042	0	0	0.042	0.125	0.167	0.167	0.083	0.125	0.16667	0	0	0

	V1	V2	V3	V4	V5	V6	V7
V1	0.056	0.115	0.16	0.106	0.155	0.219	0.173
V2	0.192	0.065	0.250	0.15	0.222	0.220	0.185
V3	0.036	0.038	0.044	0.029	0.066	0.214	0.167
V4	0.128	0.156	0.194	0.053	0.184	0.233	0.208
V5	0.029	0.025	0.073	0.027	0.038	0.179	0.057
V6	0.048	0.027	0.037	0.046	0.098	0.045	0.038
V7	0.083	0.132	0.190	0.044	0.222	0.227	0.069

Table A4.
Defuzzify matrix

CP	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	CP9
Most imp (CP1)	2	1	4	3	6	5	4	9	7
Least imp (CP1)	8	7	5	6	3	4	5	1	2

Table A5.
Response by expert 1 for capabilities importance

Capabilities of GMSC	Selected as best by expert	Selected as a worst by expert
CP1	2,5,7,8,10,11	19, 22
CP2	1,4,6,13,15	16, 24,26
CP3	3,9,12	11, 14,15
CP4	16,26	10,13,20
CP5	17, 19,20,21	7
CP6	22,24,27	23
CP7	14,23	21
CP8	–	1,2, 4,5,8,18,25
CP9	18,25	3,6,9,12,17,27

Table A6.
Best and worst attributes identified by experts from 1 to 27

Expert	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9	KSI
1	0.079	0.304	0.065	0.056	0.196	0.131	0.098	0.027	0.044	0.089
2	0.302	0.181	0.091	0.121	0.060	0.072	0.091	0.030	0.052	0.060
3	0.059	0.068	0.274	0.205	0.103	0.082	0.137	0.046	0.027	0.137
4	0.098	0.298	0.056	0.066	0.131	0.197	0.079	0.025	0.049	0.096
5	0.308	0.194	0.055	0.049	0.129	0.078	0.097	0.025	0.065	0.080
6	0.082	0.277	0.068	0.058	0.136	0.204	0.102	0.045	0.029	0.131
7	0.309	0.194	0.065	0.055	0.029	0.097	0.078	0.129	0.043	0.079
9	0.072	0.054	0.284	0.202	0.144	0.108	0.062	0.048	0.027	0.147
10	0.290	0.081	0.051	0.025	0.203	0.136	0.102	0.045	0.068	0.117
11	0.295	0.201	0.027	0.067	0.101	0.134	0.080	0.050	0.045	0.107
12	0.083	0.046	0.272	0.069	0.208	0.104	0.139	0.052	0.025	0.145
14	0.099	0.066	0.025	0.079	0.131	0.197	0.298	0.049	0.056	0.097
15	0.138	0.279	0.024	0.069	0.207	0.083	0.103	0.046	0.052	0.134
16	0.066	0.025	0.198	0.299	0.132	0.079	0.099	0.044	0.057	0.097

(*continued*)

Table A7.
Final results for ranking capabilities

Expert	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9	KSI
17	0.050	0.101	0.081	0.067	0.294	0.134	0.202	0.045	0.026	0.110
18	0.078	0.043	0.194	0.129	0.097	0.065	0.055	0.029	0.309	0.079
21	0.137	0.103	0.082	0.046	0.286	0.059	0.032	0.205	0.051	0.124
22	0.034	0.054	0.062	0.086	0.216	0.284	0.144	0.048	0.072	0.149
23	0.099	0.057	0.066	0.079	0.198	0.025	0.299	0.044	0.132	0.097
24	0.102	0.025	0.081	0.068	0.203	0.290	0.136	0.045	0.051	0.117
25	0.200	0.134	0.080	0.067	0.100	0.057	0.045	0.023	0.294	0.107
26	0.132	0.025	0.066	0.299	0.198	0.099	0.079	0.044	0.057	0.097
27	0.099	0.131	0.079	0.056	0.197	0.298	0.066	0.049	0.025	0.097
AVG	0.140	0.128	0.102	0.101	0.161	0.131	0.114	0.052	0.072	0.108
Rank	2	4	6	7	1	3	5	9	8	

Table A7.

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