Journal of Infrastructure, Policy and Development 2024, 8(10), 5539.
https://doi.org/10.24294/jipd.v8i10.5539

Article

Navigating supply chain vulnerability: A case study of resilience in Pakistan's large-scale manufacturing sector

Zeeshan Asim[1,*], Shahryar Sorooshian[2,*], Asokan Vasudevan[3], Yusri Yosof[4], Tianjiao Huang[5]

[1] College of Business, University of Buraimi, Al Buraimi 512, Oman
[2] Department of Business Administration, University of Gothenburg, Box 10040530 Gothenburg, Sweden
[3] Faculty of Business and Communications, INTI International University, Negeri Sembilan 71800, Malaysia
[4] Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Johor 86400, Malaysia
[5] Faculty of Liberal Arts, Shinawatra University, Pathum Thani 12160, Thailand
*** Corresponding authors:** Shahryar Sorooshian, shahryar.sorooshian@gu.se; Zeeshan Asim, zeeshan.a@uob.edu.om

CITATION

Asim Z, Sorooshian S, Vasudevan A, et al. (2024). Navigating supply chain vulnerability: A case study of resilience in Pakistan's large-scale manufacturing sector. Journal of Infrastructure, Policy and Development. 8(10): 5539.
https://doi.org/10.24294/jipd.v8i10.5539

ARTICLE INFO

Received: 29 March 2024
Accepted: 9 May 2024
Available online: 25 September 2024

Abstract: In the face of growing disruptions within the unconventional business environment, this study focuses on enhancing supply chain resilience through strategically reforming resources. It highlights the importance of understanding the dynamics and interactions of resources to tackle supply chain vulnerability (SCV) in the manufacturing sector. Employing the Decision-Making Trial and Evaluation Laboratory (DEMATEL) methodology alongside an adapted Analytic Network Process (ANP), the research investigates supply chain vulnerabilities in Pakistan's large-scale manufacturing (LSM) public sector firms. The DANP method, through expert questionnaires, helps validate a theoretical framework by assessing the interconnectedness of supply chain readiness dimensions and criteria. Findings underscore Resource Reformation (RR) as a critical dimension, with the positive restructuring of resources identified as pivotal for public sector firms to align their operations with disruption magnitudes, advocating for a detailed analysis of resource utilization.

Keywords: supply chain vulnerability (SCV); resilient infrastructure; efficient resource; economic growth; supply chain resilience (SCR); resource reformation (RR)

1. Introduction

The current (ab) normal in the business landscape is characterized by an uncertain and intricate environment where companies encounter disruptions to their supply chains (Sheffi, 2020). And managing disruption allow firms to become more resilient by focus on factors that enables supply chain dynamism along with resource reformation that used to assess the overall risk across the supply chain (Lee et al., 2016; Pettit et al., 2010).

Understanding the effective strategies for managing supply chain disruption relies heavily on comprehending the nature of resources and their interactions across organizational boundaries. This knowledge is crucial in enhancing our grasp of response, resilience, and restoration (Bygballe et al., 2023). Consequently, comprehending how businesses can effectively handle disruptions in the supply chain has emerged as a significant subject of interest for both scholars and industry professionals (Blackhurst et al., 2011). A disruption in the supply chain refers to an occurrence that hinders the smooth progression of goods or services, information, and financial transactions throughout the entire supply chain (Ambulkar et al., 2015).

According to a recent survey conducted by McKinsey, it was found that 83% of supply chain leaders from different organizations concur with the notion that having a resilient footprint across the supply chain enables firms to mitigate the impact of disruptions, especially in the past two years as part of the post-pandemic new normal (Knut Alicke et al., 2022). The World Economic Forum has recently launched an initiative aimed at guiding companies in addressing disruptions in the global value chain caused by factors such as geopolitical tensions, environmental disasters, and the rapid advancement of technology (WEF, 2020). In recent times, the outbreak of the pandemic has impacted the availability of numerous global supply chains (El Baz and Ruel, 2021).

The aftermath of the pandemic has highlighted the importance of enhancing the resilience of supply chains. However, among some businesses the concept of building resilience against disruption is not understated comprehensively (Ambulkar et al., 2015). Supply chain resilience encompasses the capacity of a supply chain to anticipate, respond to, and recover from disruptions in a prompt and efficient manner (Bygballe et al., 2023). Resource reformation is regarded as a fundamental element in the establishment of supply chain resilience (Bygballe et al., 2023). Supply chain resilience research has found that resource reformation and supply chain dynamism that forces firms to adapt to the change help companies mitigate and respond to risks (Bygballe et al., 2023; Lee et al., 2016; Pettit et al., 2010). Gölgeci and Kuivalainen (2020) express that supply chain resilience allows companies to quickly recover to normal level in the face of supply chain disruption. According to them supply chain resilience enables companies to swiftly restore operations to a normal level when confronted with disruptions in the supply chain (Gölgeci and Kuivalainen, 2020). Therefore, in this study, the author aimed to investigate the factors that evaluate the analytical aspects related to vulnerability, enabling firms to withstand disruptions by effectively perceiving the dynamic nature of the supply chain and establishing resources reformation throughout the supply chain network.

2. Literature review

2.1. Background on complexity in supply chain

In recent times, the growing occurrence of both natural and manmade disasters has prompted researchers and industry experts to place greater emphasis on the concept of supply chain vulnerability (SCV) (Ambulkar et al., 2015). Supply chain vulnerability (SCV) refers to the susceptibility of a company's supply chain to different risk events that can lead to disruptions in its operations (Sharma et al., 2022). The role of supply chain among manufacturing sector has regarded as one of most significant contributors to drive across developing economics (Khokhar et al., 2020).

Preparedness for supply chain vulnerability (SCV) is essential to prevent supply chain disruptions. SCV analysis entails assessing the structure of the supply chain and associated management practices that could potentially increase the susceptibility of the supply chain to risks or disruptions. Manufacturing firms should strive to reduce their SCV by strengthening their readiness in-term of assessing supply chain resilience (Kumar et al., 2020; Sharma et al., 2022). According to existing literature, certain manufacturing firms have implemented measures to mitigate their supply chain vulnerability (Sheffi, 2020). However, this trend is not widespread or commonly observed. Aman et al. (2023) highlighting SC vulnerability and emphasizing resource reconfiguration, supply network structure, social capital; calls for industrial testing, SCOR integration by practitioners, policymakers for COVID-19 resilience in developing regions (Aman and Seuring, 2023). Extensive efforts have been dedicated to the domain of supply chain risk management (SCRM). Modelling of supply chain risks has been in focus by researchers. Designing of supply chain risks (Chopra and ManMohan, 2014; Rajesh, 2019; Xu et al., 2015). But over the period of time significance on readiness regarding supply chain vulnerability has not been exposed extensively. More focus was made on improving readiness on supply chain resilience (Chowdhury and Quaddus, 2016).

Various quantitative models have been attempted by researchers to quantify SCV (Supply Chain Vulnerability). Kurdi et al. (2023) devised a quantitative framework utilizing a practical cluster sampling technique, emphasizing the importance of adopting a supply chain risk management approach within the context of Food 4.0 to bolster organizational efficiency (Kurdi et al., 2023). Al-Shboul et al. (2023) performed a quantitative survey-based study to analyze the substantial roles of Supply chain absorptive capacity, Supply chain risk mitigation, Supply chain Agility (Nelson and Ricardo) and Supply chain integration on supply chain efficacy (SCE) (Al-Shboul and Alsmairat, 2023). Nguyen et al. (2023) estimate quantitative risk analysis (QRA) of container shipping operational risk (CSOR) (Nguyen et al., 2023). Rajesh (2023) research proposes an advanced quantitative causal model aimed at assessing and depicting the cause-and-effect connections (event-outcome) within the supply chain's Grey Causal Modelling (GCM) framework (Rajesh, 2023). The primary emphasis lies on exploring the perspectives of risk resilience and sustainability in the manufacturing sector. Alsmairat et al. (2023) constructed a sophisticated quantitative framework to investigate the correlation between supply chain risk and lean manufacturing while also assessing the mediating function of supply chain resilience among manufacturing companies (Alsmairat et al., 2023). Within the realm of supply chain risks, scholars have utilized Petri nets as a methodology for evaluating the performance of supply chains (Khilwani et al., 2011; Tuncel and Alpan, 2010). Idris et al. (2023) formulated a sophisticated quantitative model with the aim of ascertaining the impact of supply chain integration capabilities on the operational performance of manufacturing companies (Idris et al., 2023). This was achieved by considering green supply chain management as a mediator in the relationship.

Yosef et al. (2023) employed a quantitative approach to discern and categorize sustainable supply chain practices (SSCM) based on the three dimensions of sustainability embodied in the triple bottom line (TBL) (Yosef et al., 2023). Pandey et al. (2021) conducted an analysis of supply chain risks within Industry 4.0 settings, stemming from technological disruptions. Within the realm of Supply Chain Risk Management (SCRM) literature, there is an abundance of information pertaining to supply chain risk and various quantification risk models (Pandey et al., 2021). However, there remains a lack of extensive research on the quantification of readiness related to Supply Chain Vulnerability. There is little clarity among interdependency among fundamental factors that explore the causative relationship and repercussions of supply chain vulnerability. The current literature highlights the extrinsic readiness factors related supply chain vulnerability with supply chain design perspective such as more emphasis on resource reformation among manufacturing firm as organism that allow supply chain processes to sense supply chain vulnerability and more focus on supply chain resilience factors in response to vulnerability appear in future, are considered. Despite the presence of factors influencing SCV in the current literature review, deficiencies persist in the reviews addressing Supply Chain Vulnerability (SCV). Only considering the general dimensions of extrinsic factors that allow to re-adjust the intrinsic factors however manufacturing firms depends on to drivers related to backward and forward integration that rise the complexity among supplier arrangements with respect to supply and demand. Various supply chain risk management model has been devised by researchers, yet model based on readiness of supply chain vulnerability (SCV), the fundamental prerequisite of supply chain risk management SCRM, remains inadequately explored, particularly with regard to the investigation of its mutual interdependency (Sharma et al., 2022). In order to close the current research disparities, our study aims to explore initial exterior readiness dimensions of SCV in manufacturing firms which influence each other. Additionally, the study will endeavor to address the following research question.

i RQ1: What are the major extrinsic dimensions responsible for orienting manufacturing firms against supply chain disruption?

ii RQ2: How can these dimensions mutually interdepend from a readiness perspective to re-adjust based on any vulnerability against supply chain disruption?

The present body of research encompasses various studies that explore how to deal with and recover from disruptions. Most of the analyzed literature delves into supply chain risk management (SCRM) strategies, with a primary focus on recovery (Rahman et al., 2022). In contrast, there exists only a limited number of papers that discuss preparedness and response strategies. Considerable emphasis has been placed on bridging the gap that currently exists between research on supply chains and the elements of an organization's external environment (Stephens et al., 2022). Given the highly dynamic attributes of contemporary supply chains, it becomes crucial to adopt a theoretical framework that harmonizes with the natural trends that have arisen from such fluidity. The S-O-R (stimulus-organism-response) framework appears to be a fitting theory, as it portrays the organization as an organism existing within a dynamic and ever-evolving context, analogous to companies operating within turbulent supply chains.

2.2. Theoretical understanding on S-O-R

The origin of the S-O-R theory in psychology finds its roots in Thorndike's seminal work, the Law of Effect, or the Stimulus-Response (S-R) theory, dating back to 1898 (Mehrabian et al., 1974). According to this theory, behavioral responses (R) that lead to favorable outcomes are more inclined to endure when confronted with a similar stimulus (S) (Mehrabian et al., 1974; Stephens et al., 2022). Recent explorations into the model have enhanced its ability to explain and evaluate diverse aspects of various dimensions to address causative relationship among extrinsic dynamism and intrinsic resources (Stephens et al., 2022). Kim et al. (2019) proposed that as situations progress, real-life experiences function as stimuli, whereas cognitive and emotional reactions are embodied as organisms, and consumers' intentions to visit certain places are revealed through their responses (Kim et al., 2019). The dynamic nature of this stimulus-driven behavior leads organizations to adapt and enhance internal processes (both cognitive and emotional) to derive greater value from their responses to environmental stimuli. Under such circumstances, resource reformation acts as a firm organism an intrinsic dimension, adjusting organizational processes to aware with successful response to supply chain vulnerability (Ambulkar et al., 2015). In supply chain perspective Consequently, within the SOR framework, an organism serves as a linkage through which an organization can substantiate its responses to the competitive environment and the decisions that influence organization to reconfigures its resilience based on vulnerability (Stephens et al., 2022). Consequently, supply chain resilience links as response' element of the SOR model. Studies suggest that organizations aim to swiftly recuperate operations after a supply chain vulnerability identified by achieving rapid recovery through aligning their resources (Chowdhury and Quaddus, 2016; Saurabh Ambulkar et al., 2015) as shown in **Figure 1**.

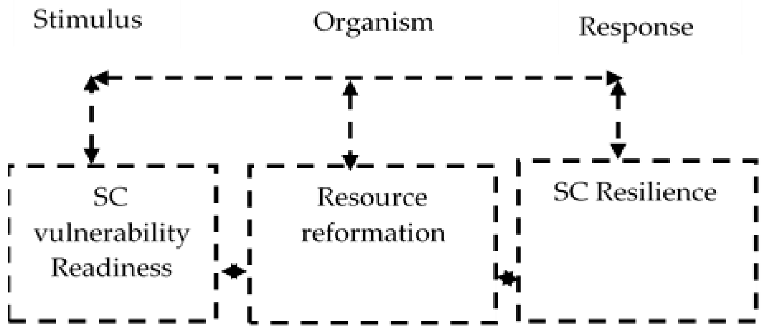

Figure 1. S-O-R model against supply chain disruption.

The intricacy is gauged by the presence of several nodes (stage or member) and intricate interconnections among these nodes (Oger et al., 2020). Decisions regarding Supply chain network design have a significant impact on the network's resilience. Within the supply chain structure, the readiness of SCV is subject to the influence of various factors such as supply chain complexity, centralized manufacturing and distribution, supplier concentration, and risk due to less room of flexibility towards a part of development (Bak, 2018; Bode and Wagner., 2015; Shih, 2020; Turner et al., 2018; Xu et al., 2019). Similarly, manufacturing firms establishing dynamic collaboration and seamless integration throughout various phases is imperative for enhancing supply chain efficiency (Mishra et al., 2022). Also, to achieve long term strategic objectives most manufacturing firms are looking for comprehensive knowledge that serves as the paramount catalyst for enhancing supply chain efficiency. The unobstructed dissemination of information and the prompt and precise access to information are crucial for making informed decisions within the supply chain. Any disruption in the transmission of information in the upstream supply chain is termed the bullwhip effect (Abdel-Basset and Mohamed., 2020; Sharma et al., 2022).

Most manufacturing firms extensively maintaining confidentiality involve the management of theft and the prevention of illicit activities within the supply chain. Ensuring supply chain security can be achieved by employing technological solutions such as implementing block chain throughout the entire supply chain process (Min, 2019; Sawik, 2021; Waller et al., 2008). Hence, the criteria related to Supply chain vulnerability can be shown as in **Table 1**.

Table 1. SCV as dimension with Criteria's.

Dimension	Criteria	Definitions	Authors
SC vulnerability Readiness	Supply Chain Efficiency	Supply chain configurations must assess the trade-offs between efficiency and resilience. To make such decisions, it is crucial to conduct vulnerability assessments and comprehend the factors that contribute to vulnerability.	(Munir et al., 2020; Pettit et al., 2019; Stecke and Kumar, 2009)
	Supply Chain Collaboration	Establishing dynamic supply chain collaboration and seamless integration across various stages is imperative to enhance supply chain performance.	(Mishra et al., 2022; Silva and Figueiredo, 2020; Sharma et al., 2022; Zeng and Yen., 2017)
	Supply chain structure	The supply chain configuration is depicted by the arrangement of its components, signifying the number of stages and multiple members within each stage. Its intricacy is gauged by the presence of numerous nodes (stages or members) and the intricate interconnections among them.	(Oger et al., 2020; Paksoy et al., 2019; Sharma et al., 2022)
	Supply chain information	Data serves as the paramount catalyst for supply chain performance. The seamless flow of information and prompt, precise access to data is crucial for making effective supply chain decisions.	(Abdel-Basset and Mohamed., 2020; Paksoy et al., 2019; Petersen et al., 2005; Sharma et al., 2022)
	Supply Chain Security	SCS issues revolve around the prevention of theft and the deterrence of illicit activities within the supply chain. Achieving supply chain security can be assured by employing technical solutions, such as implementing block chain technology across the entire supply chain process.	(Min, 2019; Sawik, 2021; Waller et al., 2008)

In the current business climate, enterprises, particularly those in developing nations, are actively pursuing global competitiveness by prioritizing supply chain management (Foundation, 2022; Sharma et al., 2023). Identifying segments within the supply chain that are particularly susceptible to disruptions is a crucial measure in mitigating their frequency and impact, which could otherwise disrupt the flow of operations.

Preparedness for supply chain vulnerability (SCV) is essential to prevent supply chain disruptions. SCV analysis entails assessing the structure of the supply chain and associated management practices that could potentially increase susceptibility to risks or disruptions. Manufacturing firms should strive to reduce their SCV by strengthening their readiness in terms of assessing existing vulnerabilities to disruption (Kumar et al., 2020; Sharma et al., 2022). According to existing literature, manufacturing firms have implemented various measures to mitigate their supply chain vulnerability. However, this trend is not widespread or commonly observed in developing countries. There are few studies that highlight the factors behind the potential criteria of Preparedness for supply chain vulnerability (SCV), which contribute significantly to understanding this concept.

Abdel-Basset and Mohamed (2020) emphasize the supply chain structure as a potential criterion for gauging SC vulnerability, particularly focusing on the number of nodes, direct and indirect links, global sourcing, and low in-house production as potential drivers. Additionally, establishing dynamic partnerships and fostering integration across various tiers of the supply chain are essential components of supply chain management. Each participating entity functions as a separate entity with its own strategic goals, performance metrics, and operational protocols. Consequently, members of the supply chain strive to optimize their individual performance efficiency rather than considering the overall performance of the supply chain, leading to significant dissatisfaction within the supply chain. In this context, Abdel-Basset and Mohamed (2020) highlighted supply chain collaboration as a potential criterion that manufacturing firms need to cultivate connections among suppliers within the supply chain to attain flexibility, efficacy, and a sustainable competitive edge. Effective information flow within the supply chain is essential for informed managerial decision-making (Paksoy et al., 2019). Demand information cascades upstream through successive members of the supply chain, with each member passing this crucial information to their immediate counterparts. As demand information travels from the end customer to the ultimate source of supply, it is common for distortions to occur along the way, making the entire system vulnerable (Sharma et al., 2022). Paksoy et al. (2019) emphasized supply chain information as a potential criterion that allows entities within the supply chain to absorb seamless flow of information, and prompt, precise access to data is crucial for making effective supply chain decisions. Furthermore, another significant factor that creates vulnerability at both internal and external levels is supply chain efficiency, which pertains to the degree to which an organization's resources, processes, and activities are susceptible to disruptions or disturbances that could hinder the timely delivery of products or services to customers, thereby potentially increasing costs and reducing value. Munir et al. (2020) underline supply chain efficiency as a potential criterion to gauge readiness related to supply chain vulnerability (SCV). Manufacturing firms need to entail low-cost sourcing, rely more on single sourcing, potentially enable lean operations, and prioritize cost containment to recover costs. Likewise, another notable aspect contributing to vulnerability that several manufacturing firms face is supply chain security, which encompasses concerns related to preventing theft and deterring illicit activities within the supply chain. Sawik (2021) and Sharma et al. (2022) feature supply chain security as a potential criterion to ensure the adoption of various measures, including the utilization of technical solutions like implementing secure technology throughout the entirety of the supply chain process.

On the other hand, the capacity to efficiently handle resources and adapt them to suit the environmental context is paramount for a firm's survival and exceptional performance (Davis et al., 2009). Supply chain disruptions are occurrences distinguished by significant unpredictability (Bode et al., 2011). The substantial unpredictability surrounding supply chain disruptions leads to uncertainty regarding the effectiveness and significance of current resources in facilitating recovery from such events (Sirmon et al., 2007). When confronted with disruptions, organizations might identify new threats or opportunities and find it necessary to revamp, reorganize, or adjust their risk management framework to address threats and seize opportunities. In scenarios of heightened uncertainty, like new product development or market entry, a firm's capacity to revamp and adapt its resource foundation has been demonstrated to be vital in cultivating capabilities that contribute to the firm's survival and expansion (Sirmon et al., 2007). According to Helfat et al. (2007), firms must rearrange and readjust their current innovation resources and processes to bolster their capacity for innovation and effectively adapt to market changes.

Bode et al. (2011) observe that the impetus to act is influenced by the magnitude of the disruption's impact. Resource reconfiguration may not be essential to achieve resilience when the disruption's severity is minimal. Take, for instance, low-impact supply disruptions, such as delayed shipments or suppliers' delivery of incorrect parts (Ambulkar et al., 2015). Therefore, the criteria related to Resource Reformation can be shown in **Table 2**.

Table 2. Resource reformation (RR) as dimension with criteria's.

Dimension	Criteria	Definitions	Authors
Resource Reformation	Restore Resource	Adjusting the allocation of organizational resources and modifying operational processes in order to adapt to shifts in the external environment.	(Ambulkar et al., 2015; Bhattacharya et al., 2023; Bygballe et al., 2023; Wei and Wang, 2010)
	Reconfigure Resource	Revamp organizational resources and operational processes in order to effectively respond to the ever-changing environment.	(Ambulkar et al., 2015; Garlick et al., 2020; Kähkönen et al., 2023)
	Response	Revise the allocation of resources in order to effectively respond to the evolving business environment.	(Ambulkar et al., 2015; Cardoso et al., 2023; Dubey et al., 2020)
	Renew Resource	Revitalize the resource foundation in order to adapt to the dynamic business environment.	(Ambulkar et al., 2015; Alexander et al., 2023; Yontar, 2023)

Resource reconfiguration emerges as a pivotal concept for large scale manufacturing sector, particularly in developing nations grappling with significant supply chain disruptions (Gracia et al., 2020). Let us delve into the strategies firms can employ to adjust their resource foundation and endure these disruptions.

The ability of firms to reform their resources is crucial for their adaptive capacity and resilience during supply chain disruptions (Ambulkar et al., 2015). However, manufacturing firms in developing countries often lack awareness of supply chain disruption orientation at a large scale, hindering their engagement in resource reconfiguration (Foundation, 2022). Firms oriented towards supply chain disruption are cognizant of potential disruptions based on past experiences and are driven to learn from them. They proactively adjust and manage resources to address supply chain disruptions. Therefore, this research provides insight for policymakers, particularly in developing nations, to improve the identification of underlying criteria supporting effective resource reform in response to supply chain disruptions, including restoring, reconfiguring, responding, and renewing resources (Ambulkar et al., 2015; Bhattacharya et al., 2023; Bygballe et al., 2023; Dubey et al., 2020; Wei and Wang, 2010).

A significant portion of the supply chain literature asserts that resources are pivotal in developing adaptive capacities to effectively address disruptions. Al Naimi et al. (2021) emphasized the necessity of possessing the capability to oversee, adapt, and restore resources in response to a dynamic environment. Al Naimi et al. (2021) refer to resource restoration as a potential criterion behind firm's ability to resist disruptions, with factors such as human capital, organizational and interorganizational capital, and physical capital driving resources towards normalization. However, Ambulkar et al. (2015) argue that the manufacturing sector demonstrating swift resource reconfiguration is a potential criterion associated with positive impact and greater resilience compared to those that do not. They conclude that a firm should evaluate its current resource portfolio based on new competencies, discard obsolete ones, or reassemble/restructure existing resources accordingly.

Similarly, manufacturing firms streamline their capacity of a supply chain to anticipate, respond to, and recover from disruptions in a prompt and efficient manner. According to Hendricks and Singhal those emphasize the significance of cultivating resilience as firms confront disruptions and advocate for further research in this domain (Hendricks and Singhal, 2005). While resilience may hold the key to a firm's capacity to handle supply chain disruptions, there exists limited exploration on how firms actually develop resilience in the face of such disruptions. The absence of a cohesive definition of resilience has contributed to the vagueness surrounding the concept of resilience in the context of supply chain disruptions, as highlighted. The present research extends the knowledge on resilience and supply chain disruptions by expanding upon the studies conducted by Bhamra et al. (2011), Ponomarov and Holcomb (2009), and Wieland and Wallenburg (2013). Our distinctive contribution involves establishing, implementing, and verifying the concept of firm resilience to supply chain disruptions, alongside exploring the factors that promote resilience development in firms facing supply chain disruptions. Gilliam and Voss (2013) coin the term "firm's resilience to supply chain disruptions" denotes the firm's capacity to remain vigilant, adapt effectively, and promptly respond to the changes caused by a supply chain disruption. According to Ambulkar et al. (2015) lead to the Gilliam and Voss (2013) work by highlighting factors that firms need to absorb the supply chain disruption are understanding the circumstance to cope with SC disruption. Similarly, Gölgeci and Kuivalainen (2020) express supply chain resilience allows companies to quickly recover to normal level in the face of supply chain disruption. According to Gölgeci and Kuivalainen (2020) supply chain resilience enables companies to swiftly restore operations to a normal level when confronted with disruptions in the supply chain.

When analyzing supply chain networks within large-scale manufacturing as adaptive systems, the ability to restructure itself to counter disruptions becomes crucial in minimizing losses caused by such disruptions. In recent years, supply chains across large scale manufacturing firms have experienced remarkable levels of instability. This includes occurrences like natural disasters, political disruptions, cyber-attacks, and shifts in market dynamics such as increased demand variability and shorter product lifecycles. Within the realm of supply chain resilience (SCR), firms abilities that signifies the supply chain's efficacy in promptly responding to and recuperating from disruptions allowing policymakers to receive preferred level direction in-term of measuring magnitude of disturbance (Gaudenzi et al., 2023; Wieland and Durach, 2021; Yan et al., 2023).

The manner in which a large-scale manufacturing entity, functioning as a system to return in equilibrium, and sustains its supply chain performance during disruptions relies on the resilience capacities of the system (Wieland and Durach, 2021). The majority of conceptual resilience literature distinguishes between 'absorption, adaptation and transformation capacities (Shin et al., 2018; Umunnakwe et al., 2021). Allowing policymakers with direction regarding the preferred level of resilience. In general, absorptive capacity is the extent of system's ability to adjust the alteration or absorb external impacts and refers to the system's vulnerability (Bruckler et al., 2024) in large scale manufacturing context ability to cope with supply chain disruption (Farrell et al., 2020; Van Hoyweghen et al., 2021). In case of uncontrollable external factor at large scale manufacturing level are Natural disaster, War while, controllable external factors are Political and Legal Uncertainty (Sharma et al., 2023). In similar fashion, adaptive capacity is a system's ability to reorganize itself to offset disruptions (Biringer et al., 2013). One of the most vital attributes of resilient supply chains is their capacity to adapt, which encompasses the ability to self-organize, evolve, and restructure their arrangement and behavior to meet new environmental conditions (Piprani et al., 2022). In terms of large scale manufacturing context, its ability to Adapt SC disruption, preventing the escalation of disturbances through maintaining control over structures and functions, and promptly recovering and responding through immediate and effective reactive plans to overcome the disruption and restore the supply chain to a resilient operational state (Dolgui and Ivanov, 2021; H¨agele et al., 2023; Rameshwar et al., 2023; Zhang et al., 2018). However, the restorative or transformative capacity refers to a system's ability to efficiently and effectively repair and response itself along with situational awareness (Bruckler et al., 2024; Hsu et al., 2021; Rezaei et al., 2021).

This research endeavors to deepen our comprehension of supply chain disruption orientation, recognizing that while it serves as a crucial foundation, it might not be adequate in isolation for fostering firm resilience. Hence, this study presents a refined collection of underlying factors that foster the establishment of firm resilience concerning supply chain disruptions through a comprehensive examination of supply chain vulnerability such as: cope with SC disruption; conceptualized and adapt SC disruption; utilizing resources to quick responded supply chain disruption; enable situational awareness across the firms (Ambulkar et al., 2015; Dolgui and Ivanov, 2021; Farrell et al., 2020; Hsu et al., 2021; Yang et al., 2021) The criteria's related to Supply Chain Resilience can be shown in **Table 3**.

Table 3. SCR as dimension with Criteria's.

Dimension	Description	Definitions	Authors
SC Resilience	Cope with SC disruption.	To manage and adjust to the alterations caused by the disruption in the supply chain	(Ambulkar et al., 2015; Farrell et al., 2020; Van Hoyweghen et al., 2021)
	Adapt SC disruption.	To easily adjust, self-organize, evolve, restructure and accommodate the challenges posed by the disruption in the supply chain.	(Ambulkar et al., 2015; Dolgui and Ivanov, 2021; Zhang et al., 2018)
	Quick Response with SC disruption	To swiftly respond to the disruption in the supply chain.	(Ambulkar et al., 2015; Chowdhury and Quaddus, 2016; Yang et al., 2021)
	Situational Awareness	To consistently uphold a strong sense of situational awareness	(Ambulkar et al., 2015; Hsu et al., 2021; Rezaei et al., 2021)

Currently, there are limited empirical studies available on supply chain resilience related to the manufacturing sector across developing countries. However, the large-scale manufacturing sector in developing countries represents a substantial portion of global supply chains and the world's population and has also encountered the detrimental consequences of supply chain breakdowns (Benjamin et al., 2017). Moreover, developing nations face heightened susceptibility to specific supply chain hazards such as political instability, encompassing rebel activities and post-election violence, as well as bribery, inadequate transportation infrastructure, corruption, and other unethical business behaviors.

This research aims to enhance our understanding of supply chain disruption orientation, recognizing that while it serves as a crucial foundation, it may not be sufficient on its own to foster firm resilience. Therefore, this study provides a framework for policymakers, especially in developing countries, to refine the collection of underlying factors that contribute to the positive establishment of firm resilience regarding supply chain disruptions. These factors include coping with supply chain disruption, conceptualizing and adapting to supply chain disruption, utilizing resources to respond quickly to supply chain disruption, and enabling situational awareness across firms (Ambulkar et al., 2015; Benjamin et al., 2017; Dolgui and Ivanov, 2021; Farrell et al., 2020; Hsu et al., 2021; Yang et al., 2021).

According to Ambulkar et al. (2015), coping with supply chain disruptions is primarily dependent on firms' absorptive capacity, which enables them to operate more flexibly, particularly during production and sourcing, allowing companies to adjust to alterations or absorb external impacts. Additionally, another significant factor on a large scale is the value of new information and knowledge sharing, which positively impacts disruption orientation (Chowdhury and Quaddus, 2017). Similarly, the ability to adapt to supply chain disruptions depends on firms' adaptive capacity, enabling them to reorganize themselves by fostering agility and efficiency (Sturm et al., 2021). Agility aids in coping with risks (Gligor et al., 2020), while efficiency is associated with quality and productivity (Ivanov et al., 2014). On the other hand, quick response within the supply chain is also considered as part of firms' adaptive capacity, linked with firm responsiveness to handle crises by reducing the impact of losses (Chowdhury and Quaddus, 2017; Yang et al., 2021). Situational awareness is often referred to as the restorative ability of firms to consistently uphold a strong sense of repair, with technological capabilities being a major criterion behind such a factor (Ghasemaghaei, 2019).

3. Research framework

Public sector manufacturing companies are seen as pivotal entities in fostering a culture centered on knowledge within emerging economies (Khokhar et al., 2020). In the pursuit of profound economic transformation, the majority of low- and middle-income developing nations regard the art of manufacturing as a creative capacity at the national level. This capacity serves as the systematic bedrock for bolstering the reservoir of knowledge. This systematic capability due to manufacturing fosters a culture of knowledge to facilitate the development of novel applications (Alkhatib and Momani, 2023). Boosting investments in supply chain assets within manufacturing firms holds the potential to enhance the likelihood of achieving elevated competitiveness on both national and regional fronts. Consequently, this empowers policymakers to channel augmented investments into supply chain capabilities within manufacturing firms, ultimately leading to a higher degree of value augmentation in terms of capital and economic advancement (Sharma et al., 2022). Emerging economies assume a vital position in the worldwide supply chain and confront supply chain disturbances. In these progressing nations, a multitude of enterprises is exposed to a multitude of risks and disturbances due to the political, economic, and cultural circumstances prevalent in these regions (Alkhatib and Momani, 2023).

In the context of Pakistan, manufacturing within the public sector serves as a direct contributor to approximately 12.79 percent of the Gross Domestic Product (GDP), and this sector employs 16.1 percent of the nation's workforce (Aamer et al., 2021). It assumes a pivotal function in fortifying the foundations of both economic and societal advancement. This is owing to its substantial impact on job creation, the attraction of high-quality investments, the entry into global markets, and the enhancement of Pakistan's product reputation and recognition (Aamer et al., 2021).

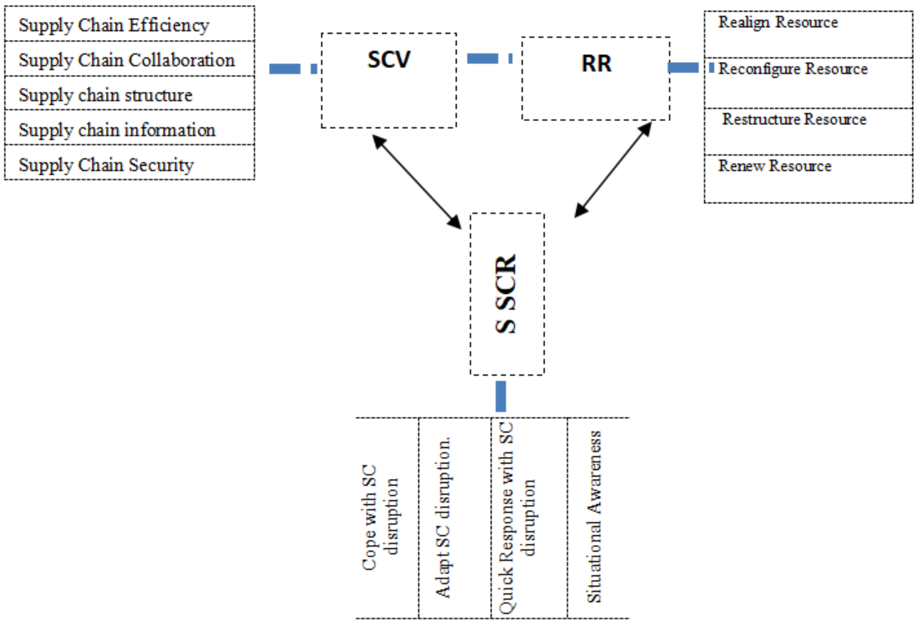

Figure 2. Research framework.

The Pakistan's manufacturing arena comprises two sub-divisions: the Large-Scale Manufacturing (LSM), which commands 9.73 percent of the GDP, predominantly dominates the overarching manufacturing sphere, representing 76.1 percent of the sector's portion. Subsequently, the Small-Scale Manufacturing, constituting 2.12 percent of the total GDP and holding a 16.6 percent sectoral stake, follows suit. (Aamer et al., 2021). This Study focuses more upon the large-scale manufacturing sector (LSM) which shares a higher contribution to GDP. Although, the significance of examining disruption-related concerns and supply chain resilience (SCR), researchers in developing nations have yet to direct their focus toward this area due to lack of clarity on cause-effect factors related to preparedness towards the supply chain vulnerability that's trigger resource reformation to developed firm resilience again any disruption among manufacturing firms (Sharma et al., 2022). The current manufacturing system at large scale owned by public organizations spread across various sectors. For example, according to Pakistan Bureau of Statistics (PBS) based the Quantum Index of Large-Scale Manufacturing (QIM) overall split among various sector is 70 % where Textile contributes 21% while, Food and Beverages contributes (12%), Petroleum (5%), Pharma contributes (12%), chemical (2%), Automobile (5%), Fertilizer (4%), Paper & Board (2%), Electronics (2%), Metal (5%) and Non-Metal (5%) (Pakistan, 2020). The theoretical model that derives from literature must be deliberated within the context specific to each country. The questionnaire based on dimension and criteria were derived research framework shown in **Figure 2**.

This study builds its conceptual framework upon theoretical evidence, offering an intricate depiction and pertinent elucidation of essential factors affecting the research breakthrough. These theoretical evidences impact specific factors essential for substantiating a research arguments centered on supply chain disruption. Moreover, the conceptual framework encompasses specific dimensions that validate critical conditions and are deemed essential for formulating a coherent interpretation to establish practical relevance.

Drawing from S-O-R theory, the conceptual framework proposed in this study evaluates the correlation between various criteria and dimensions associated with preparedness for supply chain vulnerability, internal resource reformation within firm, and the capacity of firms to uphold supply chain resilience. These elements have a direct impact on a firm's capability to manage supply chain disruptions.

The conceptualization of being prepared for vulnerabilities in the supply chain impacts, to some degree, the internal restructuring of resources within the company, especially in handling disruptions in the supply chain (Bhattacharya et al., 2023; Bygballe et al., 2023). The firm's capacity to adapt its resources is essential for resilience against supply chain disruptions. We predict that firms focused on managing supply chain disruptions are more likely to undergo resource restructuring, as they acknowledge the probability of disruptions from past encounters (Ambulkar et al., 2015).

Generally, comprehending a company's preparedness for vulnerabilities in its supply chain requires evaluating its potential capacities, encompassing the structure, efficiency, collaboration, and technological aspects of the supply chain (Sharma et al., 2022). The configuration of the supply chain illustrates the stages and the participation of various members at each stage, thereby enabling the deployment of responsive strategies to tackle potential vulnerabilities. This process entails the development and management of existing resources reformation as necessary (Sharma et al., 2022).

The current strategies for managing supply chain vulnerabilities require reassessment within the framework of resilience, which has resulted in uncertainty surrounding the concept. The term 'firm's resilience to supply chain disruptions' denotes the firm's capacity to remain vigilant, adapt adeptly, and respond promptly to changes stemming from supply chain disruptions, based on the firm's readiness for supply chain vulnerability (Ambulkar et al., 2015; Farrell et al., 2020).

The primary objectives crucial for attaining proficiency in supply chain management within the large-scale manufacturing sector, with the aim of broadening their market reach, rely significantly on the interconnectedness of firm resource restructuring and its resilience factors in mitigating disruptions within the supply chain (Ambulkar et al., 2014; Kamalahmadi and Parast, 2016).

3.1. Research design

A series of pairwise questionnaires were distributed among experts in 12 focus groups, which were organized among 109 active public sector manufacturing firms. The purpose was to measure the interrelationships among antecedent readiness factors related to supply chain vulnerability, resource reformation, and supply chain resilience. The outcomes of the focus group discussions were then analysed using a hybrid multicriteria decision-making algorithm called DANP (Al-Mawali, 2023; Asim et al., 2018). The framework employed a combination of DEMATEL and ANP techniques to examine the interrelationship among various dimensions and criteria related to antecedent readiness factors associated with supply chain vulnerability, resource reformation, and supply chain resilience, all of which impact manufacturing firms throughout their processes. The expert-approved model, based on the aforementioned research design, is illustrated below **Figure 3**.

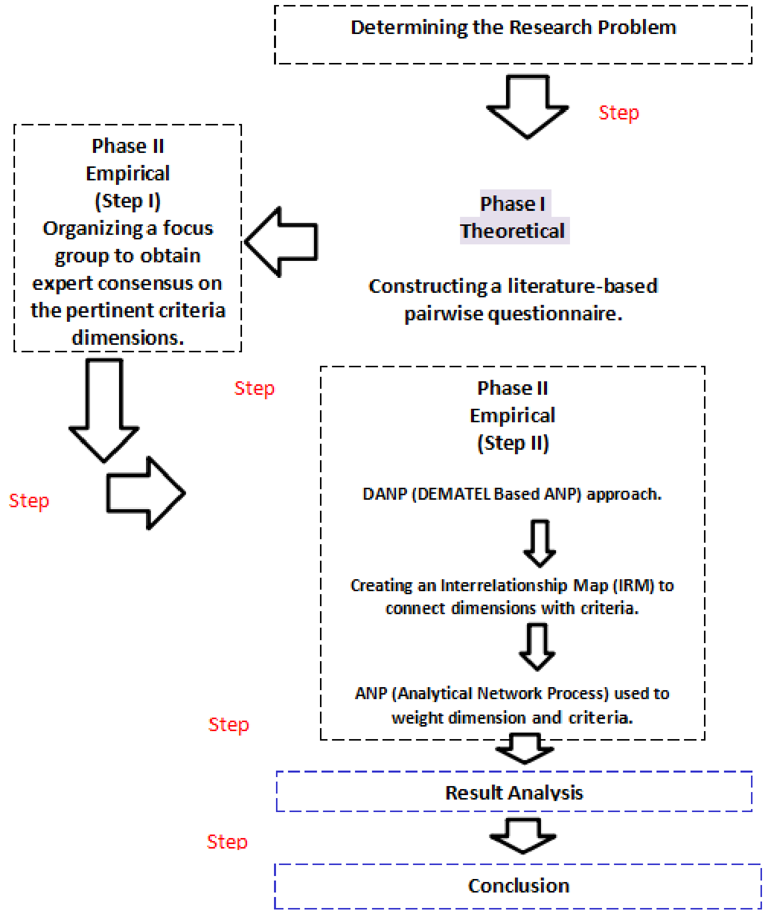

Figure 3. Proposed research design flow.

3.2. Methodology

The methodology known as the Decision-Making Trial and Evaluation Laboratory (DEMATEL), innovated under the auspices of the Science and Human Affairs Program at the Battelle Memorial Institute in Geneva between 1972 and 1976, was put to use in the exploration and resolution of intricate and interconnected collections of intricate issues (Tseng, 2009). In general, an Analytic Network Process

(ANP) rooted in the Decision Making and Trial Evaluation Laboratory (DEMATAL) approach is employed to investigate essential attributes, aiming to enhance the holistic system by transforming factor attributes into matrix representations (Asim and Sorooshian, 2022). Owing to the interlinked characteristics among the attributes inherent in the capacities linked to the supportive management domain, scholars possess the capability to harmonize with the DANP (ANP constructed on DEMATEL principles) approach (Asim and Sorooshian., 2022). Utilizing the DANP methodology, sets of pairwise comparison questionnaires have been disseminated to experts, aimed at refining the competencies within the context specific to a particular country (Asim et al., 2018). DANP has previously undergone exploration in alternative domains, encompassing areas such as electronic commerce (Chiua et al., 2013). Choice of suppliers for reclaimed resources (Hsu et al., 2014), Enhancing strategies in the tourism sector (Liu et al., 2012). The theoretical framework is validated using the DANP method to control the potential correlation between the dimensions and criteria within pertinent interrelationship linked to the readiness related to vulnerabilities of supply chain, as illustrated **Figure 4**. The DANP method, founded on DEMATEL and ANP, is divided into dual segments: (1) DEMATEL employed in the formation of the Impact Relationship Matrix (Sirmon et al., 2007) and (2) ANP employed to determine the weights of the criteria **Figure 4**.

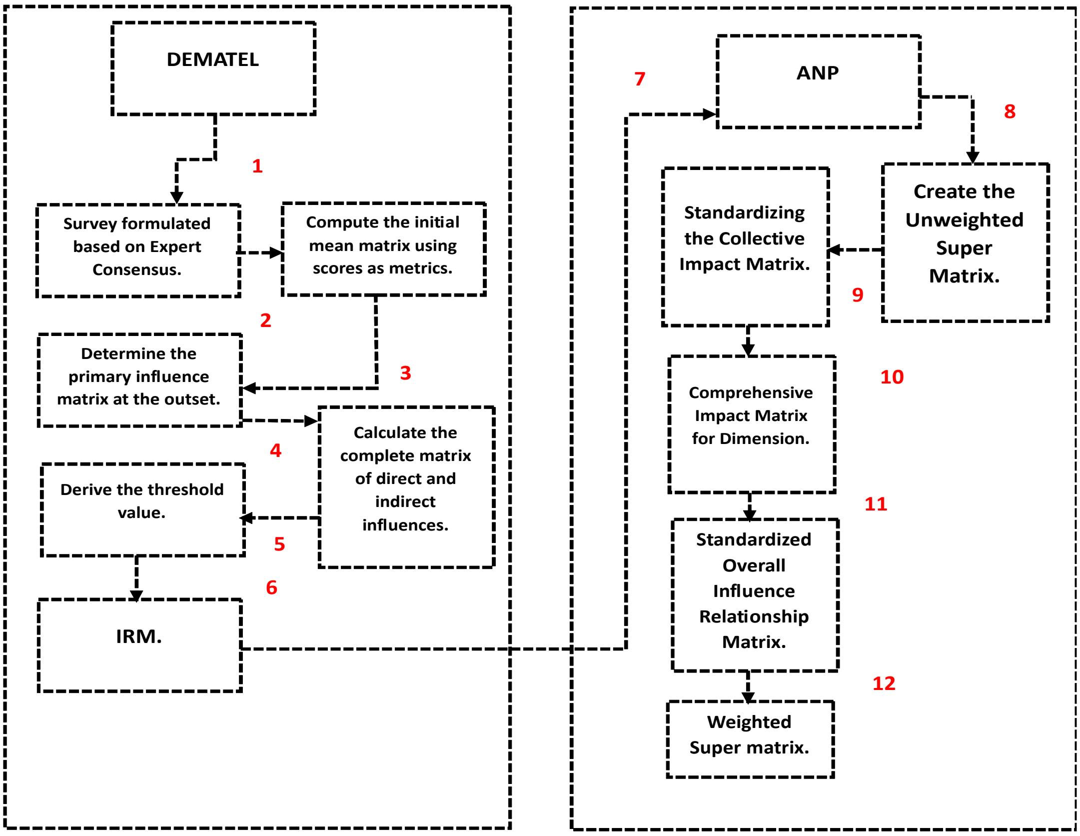

Figure 4. The DANP (DEMATEL-based ANP) approach.

3.3. The DEMATEL-based ANP (DANP) approach

DANP, which stands for the fusion of DEMATEL (Decision Making and Trial Evaluation Laboratory) and ANP (Analytic Network Process), represents an integrated implementation of decision-making methodologies. In the initial stage, DEMATEL was utilized to validate the interactions between the primary dimensions and the criteria, as well as to ascertain the degrees of these interactions (Tzeng and Huang, 2011). The DEMATEL methodology facilitates certain essential attributes employed for the enhancement of the holistic system through the conversion of factor characteristics into matrix representations. These attributes empower decision-makers to comprehend both direct and indirect impacts among them (Tzeng and Huang, 2011). DEMATEL functions not solely to validate the connections among the factors but also to attain the most precise weights. In sequence, a Novel integration of DEMATEL and ANP was implemented to generate results of greater practicality, determining the actual value across the factors involve maintaining the readiness related to vulnerabilities of supply chain across the public sector manufacturing. The feedback mechanism of ANP substitutes hierarchies with networks, enabling intricate interconnections between dimension and criteria. This complexity escalates with shifts in the scope and complexity of the decision-making problem. Harnessing this proficiency of ANP in conjunction with DEMATEL, the significant magnitudes can subsequently be ascertained, drawing upon the NRM originating from DEMATEL (Tzeng and Huang, 2011). The comprehensive sketch on DANP is represented in **Figure 5**.

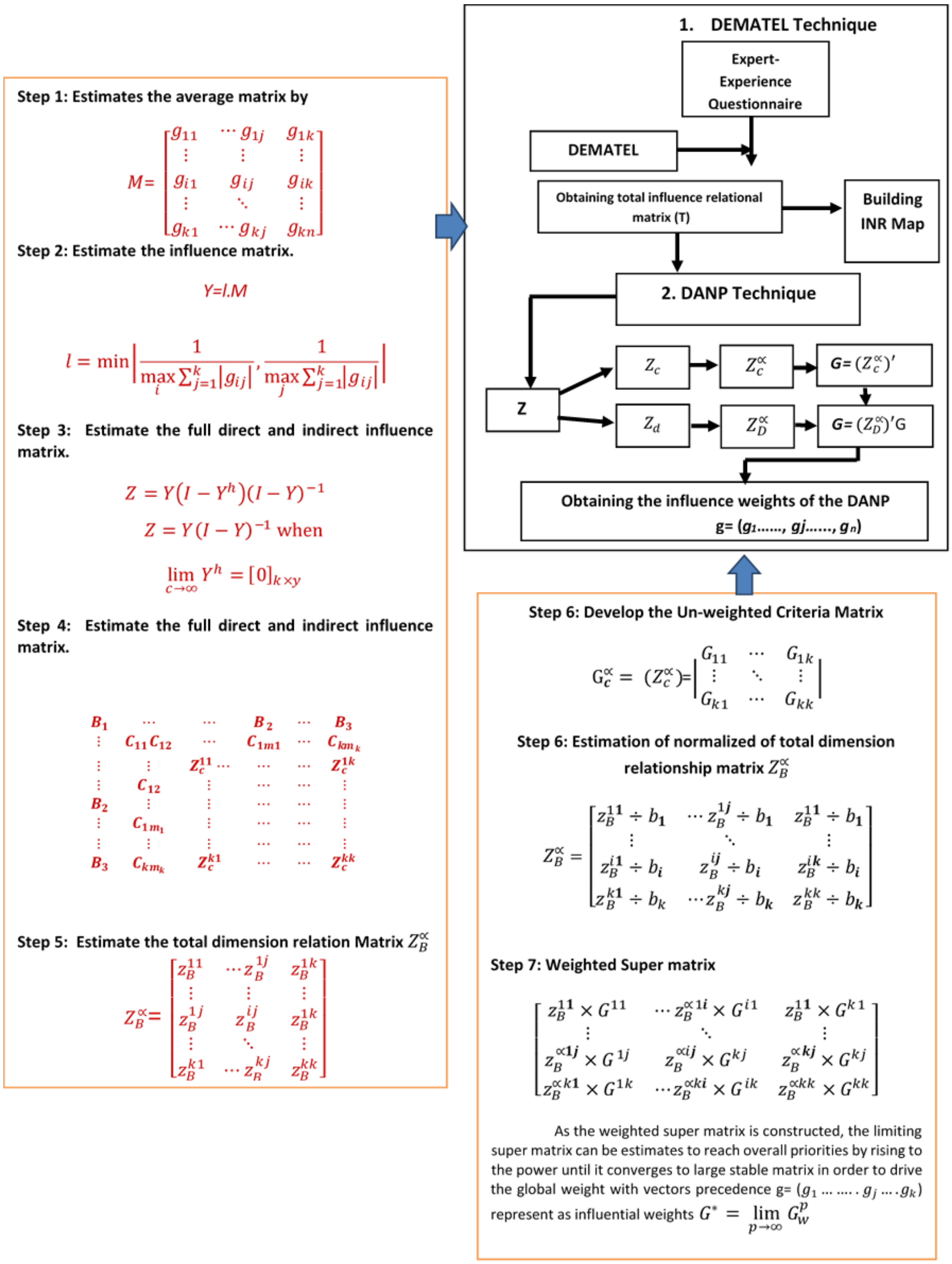

Figure 5. Complete steps of DANP methods.

3.4. Data collection

This section provides a detailed account of the expert's participation in the focus-group discussions, encompassing various aspects such as introducing the research participants, discussing the dimensions and criteria of the research theme, and facilitating the overall process.

(1) The selection criteria: The public firms involved a careful screening process, guided by the insights from (Sharma et al., 2022; Zainal Abidin, 2018). Only the active public sector manufacturing firms that demonstrated a strong focus on supply chain resilience were considered. Out of the initial pool of 109 active public sector firms, 60 were identified as active public sector manufacturing firms, while the remaining were

excluded based on significant criteria such as their organizational mission, trading corporation status, and financial nature.”

(2) “Experts from 60 active public sector manufacturing firms in Pakistan were organized into 12 focus groups based on comprehensive guidelines presented by Khokhar et al. (2020). The selection criteria for the experts included three main factors: (1) holding positions such as Managers, Senior Managers, or professional engineers with supply chain expertise; (2) involvement in supply chain resilience orientation and the development of new supply chain capabilities; and (3) positive responses to invitation letters indicating their willingness to participate. These supply chain experts, with diverse backgrounds, reached a consensus based on their collective expertise in supply chain operations. The composition of each focus group, as proposed by Colucci (2008), consisted of five experts who met specific criteria: (1) possessing a deep understanding and experience of the research theme; (2) being able to effectively present their research ideas during the discussions; (3) ensuring the formation of homogeneous groups; and (4) promoting excellent teamwork by avoiding excessive assertiveness or undue anxiety when expressing opinions.” “The research theme focused on inviting experts who shared common interests in procurement, distribution, and warehousing to participate in the focus-group discussion. The objective was to develop a consensus among the group members. To identify the relationships between dimensions and criteria, a pairwise questionnaire based on the Decision-Making Trial and Evaluation Laboratory (DANP) technique was employed.”

3.5. Analysis

A comprehensive assembly of 60 experts, constituting twelve distinct focus groups, each comprising five participants. This diverse ensemble encompassed professionals ranging from Chief Operational Managers and Professional Engineers to Managers, SCM Consultants, and Warehouse Managers. Notably, the very same group of expert panel members participated in both the focus-group dialogues and the utilization of DANP (DEMATEL-based ANP) techniques. Initially, nearly 14 focus groups were extended invitations to partake, ensuring utmost reliability of the instrument. Eventually, out of this pool, 12 groups were selected as viable discussion forums, demonstrating a favorable potential response rate. These 39 interdisciplinary focus groups wholeheartedly engaged in both sessions. The demographic particulars of the surveyed experts are comprehensively presented in **Table 4**.

Table 4. Demographic information of the surveyed experts.

Orientation	Categorize	*N*	%
Group	Chief Operational Manager	13	21.6
	Professional Engineers	10	16.6
	Manager	13	21.6
	SCM Consultants	13	21.6
	Warehouse managers	11	18.3
	Total	60(12)	100

Table 4. (*Continued*).

Orientation	**Categorize**	***N***	**%**
Gender	Male	40	66.6
	Female	20	33.3
	Total	60(12)	100%
Age	31–41	09	13.8
	41–51	27	45.6
	51–above 60	24	40
	Total	60	100%
Education	Bachelor	15	25%
	Masters	45	75%
	Total	60	
Industrial and Academic Experience	Chief Operational Manager	147.42 years	18.9
	Professional Engineers	107.4 years	17.9
	Manager	109 years	14.0
	SCM Consultants	340.6 years	26.2
	Warehouse managers	159.06 years	24.1
	Total (Industrial Experience)	863.86 years	100

4. Results

Utilizing the DANP methodology, we initially managed to explore the influence relationships based on their significance and assess the level of importance among dimensions within this research. **Tables 5** and **6** present the collective agreement within the expert group regarding the influence attributed to each criterion. The error gap ratio in **Table 6** was 4.6%, less than 5%, i.e., showing a significant confidence of 95.42%. As a result, the comprehensive mean matrix can be derived from the data in **Table 5**, and these data points can be employed in the DEMATEL technique. Step 1: Estimating the normalized initial direct-relation $Z_{(\text{Criteria})}$, as show in **Table 7** Step 2: The total criteria relation matrix $Z_{(\text{Criteria})}$ and the total dimension relation $Z_{(\text{Dimension})}$ were calculated through matrix X as shown in **Tables 8** and **9** respectively. (3) Finally, the extent to which each criterion and dimension impacted and was influenced by all the rest can be observed. As shown in **Table 10**. After performing steps 1–3, based on three steps, we were able to formulate the Interrelation Matrices (Sirmon et al., 2007) for both dimensions and criteria. The resulting IRMs are illustrated in **Figures 6–9** respectively.

Table 5. The total average matrix $Z_{(Criteria)}$ across 12 groups.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34	
C11	0.0	2.1	2.2	2.1	1.8	2.0	2.1	2.2	2.0	1.9	1.9	2.0	2.0	**24.26**
C12	2.1	0.0	1.2	2.1	1.5	1.7	2.0	2.4	2.3	2.2	1.8	1.5	1.5	**22.28**
C13	2.0	2.8	0.0	1.9	1.8	1.8	2.3	2.6	2.4	2.2	2.9	1.4	1.4	**25.47**
C14	2.0	2.3	1.1	0.0	1.7	1.9	2.1	2.6	1.6	1.6	1.8	1.8	1.8	**22.19**
C15	1.9	1.5	1.1	1.4	0.0	2.1	1.6	1.9	2.2	2.2	2.4	2.0	2.0	**22.22**
C21	1.2	1.8	1.1	1.0	1.7	0.0	2.1	2.0	1.6	2.9	2.6	2.2	1.2	**21.40**
C22	1.7	1.8	2.9	2.9	2.9	2.9	0.0	2.9	2.1	2.5	2.0	2.1	1.5	**28.21**
C23	1.2	1.5	1.5	1.3	2.1	2.5	2.5	0.0	1.4	2.5	2.4	2.3	1.5	**22.65**
C24	1.2	1.0	1.5	2.9	1.9	2.5	1.3	1.7	0.0	2.2	2.6	2.2	1.3	**22.48**
C31	2.0	1.5	1.4	1.8	2.0	2.2	2.1	2.3	2.2	0.0	1.3	2.0	2.1	**22.86**
C32	2.0	1.8	1.0	1.5	2.3	2.4	2.2	2.6	2.4	1.5	0.0	2.2	2.9	**24.84**
C33	1.9	1.8	2.9	1.8	2.4	2.6	2.0	2.4	2.6	1.3	2.4	0.0	1.8	**25.64**
C34	1.2	1.5	1.3	1.7	1.6	2.6	1.9	2.2	2.6	1.7	1.5	1.6	0.0	**21.45**
	20.43	**21.28**	**19.31**	**22.40**	**23.65**	**27.26**	**24.22**	**27.78**	**25.26**	**24.83**	**25.36**	**23.21**	**20.96**	

Table 6. The total average matrix $Z_{(Criteria)}$ across 11 groups.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34
C11	0.00	2.06	2.16	2.06	1.75	1.94	2.07	2.17	1.91	1.87	1.87	1.96	1.96
C12	2.07	0.00	1.19	2.07	1.48	1.66	1.98	2.34	2.24	2.17	1.71	1.46	1.46
C13	1.96	2.75	0.00	1.81	1.75	1.79	2.24	2.54	2.30	2.19	2.85	1.38	1.38
C14	1.97	2.20	1.09	0.00	1.66	1.87	2.02	2.56	1.56	1.57	1.75	1.75	1.75
C15	1.87	1.46	1.10	1.38	0.00	2.07	1.56	1.87	2.17	2.18	2.30	1.91	1.91
C21	1.17	1.76	1.09	0.99	1.68	0.00	2.09	1.93	1.56	2.85	2.54	2.17	1.15
C22	1.68	1.71	2.85	2.85	2.85	2.85	0.00	2.85	2.09	2.44	1.91	2.07	1.48
C23	1.15	1.48	1.46	1.28	2.10	2.44	2.46	0.00	1.32	2.49	2.30	2.24	1.46
C24	1.19	1.00	1.48	2.85	1.89	2.49	1.29	1.70	0.00	2.17	2.54	2.17	1.28
C31	1.96	1.46	1.38	1.75	1.91	2.17	2.07	2.24	2.17	0.00	1.28	1.91	2.10
C32	1.97	1.76	0.99	1.48	2.24	2.34	2.17	2.54	2.34	1.48	0.00	2.17	2.85
C33	1.87	1.71	2.85	1.75	2.30	2.54	1.91	2.30	2.54	1.28	2.30	0.00	1.75
C34	1.17	1.48	1.28	1.66	1.56	2.56	1.87	2.19	2.56	1.66	1.48	1.56	0.00

Table 7. Normalized initial direct-relation $Z_{(Criteria)}$.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34
C11	0.00	0.07	0.08	0.07	0.06	0.07	0.08	0.08	0.07	0.07	0.07	0.07	0.07
C12	0.07	0.00	0.04	0.08	0.05	0.06	0.07	0.08	0.08	0.08	0.06	0.05	0.05
C13	0.07	0.10	0.00	0.07	0.06	0.06	0.08	0.09	0.08	0.08	0.10	0.05	0.05
C14	0.07	0.08	0.04	0.00	0.06	0.07	0.07	0.09	0.06	0.06	0.06	0.06	0.06
C15	0.07	0.05	0.04	0.05	0.00	0.07	0.06	0.07	0.08	0.08	0.08	0.07	0.07
C21	0.04	0.06	0.04	0.04	0.06	0.00	0.08	0.07	0.06	0.10	0.09	0.08	0.04
C22	0.06	0.06	0.10	0.10	0.10	0.10	0.00	0.10	0.08	0.09	0.07	0.08	0.05
C23	0.04	0.05	0.05	0.05	0.08	0.09	0.09	0.00	0.05	0.09	0.08	0.08	0.05
C24	0.04	0.04	0.05	0.10	0.07	0.09	0.05	0.06	0.00	0.08	0.09	0.08	0.05
C31	0.07	0.05	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.00	0.05	0.07	0.08
C32	0.07	0.06	0.04	0.05	0.08	0.08	0.08	0.09	0.08	0.05	0.00	0.08	0.10
C33	0.07	0.06	0.10	0.06	0.08	0.09	0.07	0.08	0.09	0.05	0.08	0.00	0.06
C34	0.04	0.05	0.05	0.06	0.06	0.09	0.07	0.08	0.09	0.06	0.05	0.06	0.00

Table 8. Total relation matrix $Z_{(Criteria)}$.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34	
C11	0.29	0.37	0.35	0.39	0.40	0.45	0.41	0.46	0.42	0.42	0.42	0.40	0.37	5.16
C12	0.34	0.28	0.30	0.36	0.36	0.41	0.38	0.44	0.40	0.40	0.39	0.36	0.33	4.75
C13	0.37	0.41	0.29	0.39	0.41	0.47	0.44	0.49	0.45	0.45	0.47	0.40	0.36	5.40
C14	0.33	0.35	0.29	0.29	0.37	0.42	0.38	0.44	0.38	0.38	0.39	0.37	0.33	4.73
C15	0.33	0.33	0.29	0.34	0.31	0.43	0.37	0.42	0.40	0.40	0.41	0.37	0.34	4.73
C21	0.30	0.33	0.29	0.32	0.36	0.35	0.38	0.41	0.37	0.41	0.41	0.37	0.31	4.60
C22	0.39	0.41	0.41	0.46	0.48	0.54	0.40	0.54	0.48	0.49	0.48	0.45	0.40	5.92
C23	0.31	0.33	0.31	0.34	0.39	0.45	0.41	0.37	0.38	0.42	0.42	0.39	0.33	4.85
C24	0.31	0.31	0.31	0.39	0.38	0.44	0.36	0.42	0.33	0.40	0.42	0.38	0.32	4.78
C31	0.34	0.33	0.31	0.36	0.38	0.44	0.39	0.44	0.41	0.34	0.38	0.38	0.35	4.86
C32	0.36	0.36	0.32	0.37	0.42	0.47	0.42	0.48	0.44	0.41	0.37	0.41	0.40	5.24
C33	0.37	0.38	0.39	0.39	0.43	0.49	0.43	0.49	0.46	0.42	0.46	0.35	0.38	5.43
C34	0.30	0.32	0.29	0.34	0.35	0.43	0.37	0.42	0.40	0.37	0.37	0.35	0.26	4.56
	4.35	4.50	4.14	4.74	5.06	5.78	5.14	5.82	5.31	5.30	5.38	4.99	4.49	65.01

Table 9. Total relation matrix $Z_{(Dimension)}$.

	D1	D2	D3	
D1	2.950962	3.332028	3.273439	9.556429
D2	3.066127	2.778201	3.030072	8.8744
D3	2.827266	2.852805	2.534834	8.214905
	8.844354	8.963034	8.838345	

Table 10. Overall effects (given and received) of the total average matrix on $Z_{(\text{Dimension})}$ and $Z_{(\text{Criteria})}$.

	$Z_{(\text{Dimension})}$ and $Z_{(\text{Criteria})}$				
		$R_{(\text{row})}$	$C_{(\text{Column})}$	$R_{(\text{row})} + C_{(\text{Column})}$	$R_{(\text{row})} - C_{(\text{Column})}$
SCV	D1	2.38	2.59	4.97	−0.21
Supply Chain Efficiency	C11	5.16	4.35	9.50	0.81
Supply Chain Collaboration	C12	4.75	4.50	9.25	0.25
Supply chain structure	C13	5.40	4.14	9.54	1.26
Supply chain information	C14	4.73	4.74	9.48	−0.01
Supply Chain Security	C15	4.73	5.06	9.79	−0.33
Resource Reformation	D2	2.51	2.34	4.84	0.17
Realign Resource	C21	4.60	5.78	10.38	−1.18
Reconfigure Resource	C22	5.92	5.14	11.06	0.77
Restructure Resource	C23	4.85	5.82	10.68	−0.97
Renew Resource	C24	4.78	5.31	10.08	−0.53
SCR	D3	2.58	2.54	5.11	0.04
Cope with SC disruption.	C31	4.86	5.30	10.16	−0.44
Adapt SC disruption.	C32	5.24	5.38	10.63	−0.14
Quick Response with SC disruption	C33	5.43	4.99	10.42	0.44
Situational Awareness	**C34**	4.56	4.49	**9.05**	**0.08**

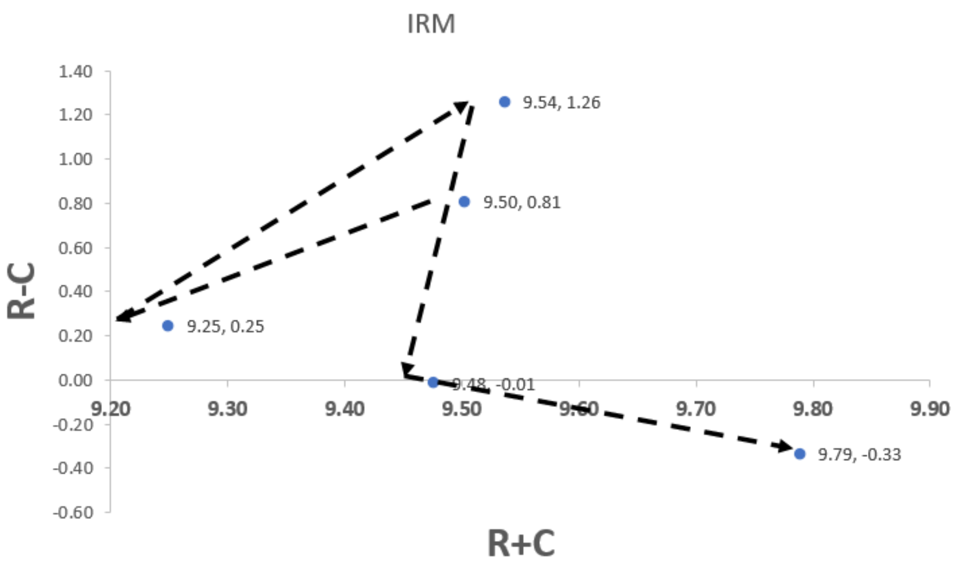

Figure 6. The IRM for the SCV (Z_{Criteria}).

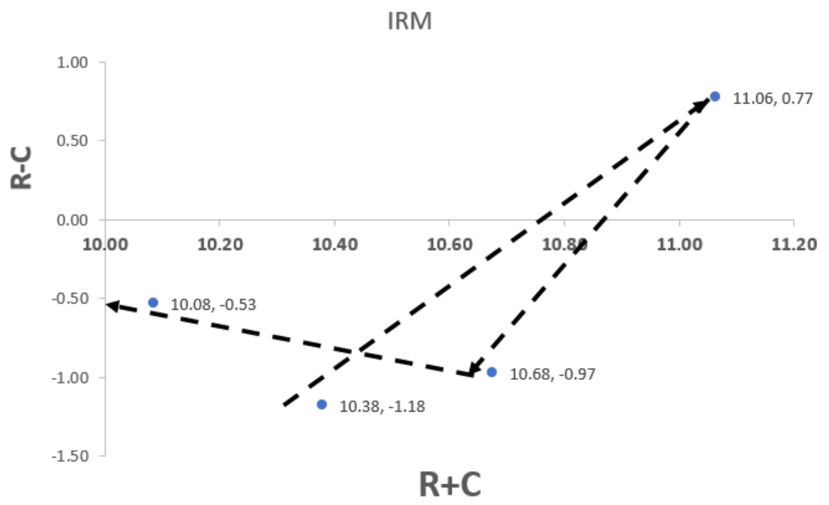

Figure 7. The IRM for the RR $Z_{(\text{Criteria})}$.

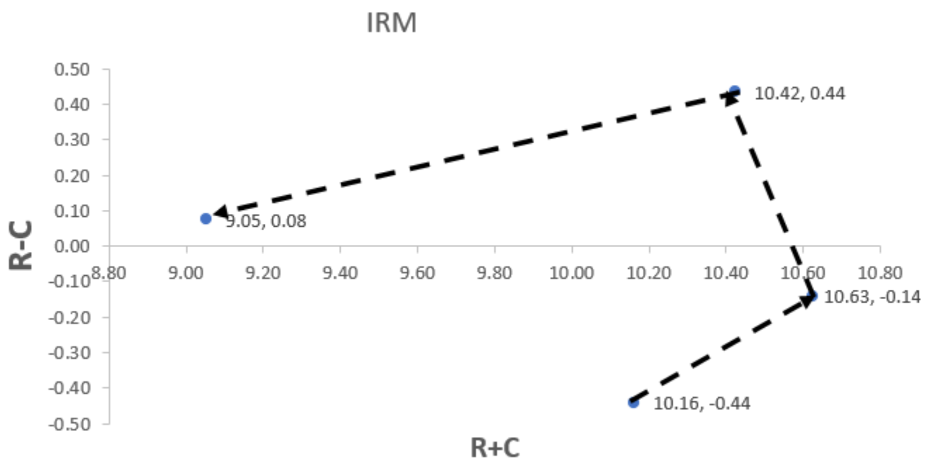

Figure 8. The IRM for the SCR $Z_{(\text{Criteria})}$.

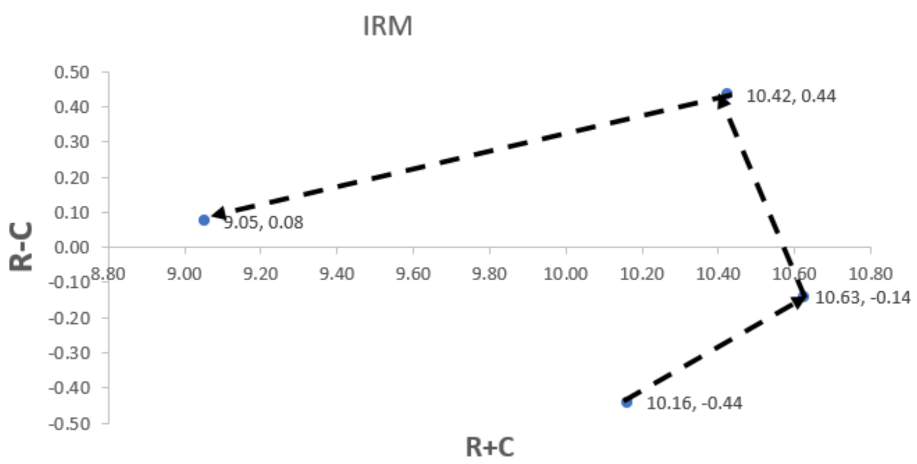

Figure 9. The IRM of dimensions.

The ANP approach, encompassing procedure step 6 through step 8, was utilized. (1) The execution of Step 6 was carried out to establish the normalized weighted matrix **Tables 11** and **12** display the outcomes of the normalized comprehensive matrix for criteria relationships and the normalized comprehensive matrix for dimensional relationships, correspondingly. (2) Step 7 was then completed. **Table 13** shows the weighted super matrix *G*. In Step 8, the $G*$ super matrix multiplied by itself ($\lim_{n\to\infty}(G^*)^n$) to create the converged stable matrix, as shown in **Table 13**.

Table 11. Normalized relation matrix $Z^{\alpha}_{(\text{Dimension})}$.

	D1	D2	D3
D1	0.274	0.351	0.376
D2	0.373	0.247	0.380
D3	0.389	0.343	0.268

Table 12. Normalized relation matrix $Z^{\alpha}_{(\text{Criteria})}$.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34
C11	0.29	0.37	0.35	0.39	0.40	0.45	0.41	0.46	0.42	0.42	0.42	0.40	0.37
C12	0.34	0.28	0.30	0.36	0.36	0.41	0.38	0.44	0.40	0.40	0.39	0.36	0.33
C13	0.37	0.41	0.29	0.39	0.41	0.47	0.44	0.49	0.45	0.45	0.47	0.40	0.36
C14	0.33	0.35	0.29	0.29	0.37	0.42	0.38	0.44	0.38	0.38	0.39	0.37	0.33
C15	0.33	0.33	0.29	0.34	0.31	0.43	0.37	0.42	0.40	0.40	0.41	0.37	0.34
C21	0.30	0.33	0.29	0.32	0.36	0.35	0.38	0.41	0.37	0.41	0.41	0.37	0.31
C22	0.39	0.41	0.41	0.46	0.48	0.54	0.40	0.54	0.48	0.49	0.48	0.45	0.40
C23	0.31	0.33	0.31	0.34	0.39	0.45	0.41	0.37	0.38	0.42	0.42	0.39	0.33
C24	0.31	0.31	0.31	0.39	0.38	0.44	0.36	0.42	0.33	0.40	0.42	0.38	0.32
C31	0.34	0.33	0.31	0.36	0.38	0.44	0.39	0.44	0.41	0.34	0.38	0.38	0.35
C32	0.36	0.36	0.32	0.37	0.42	0.47	0.42	0.48	0.44	0.41	0.37	0.41	0.40
C33	0.37	0.38	0.39	0.39	0.43	0.49	0.43	0.49	0.46	0.42	0.46	0.35	0.38
C34	0.30	0.32	0.29	0.34	0.35	0.43	0.37	0.42	0.40	0.37	0.37	0.35	0.26

Table 13. Weighted super matrix $W = Z^*_{(\text{Dimension})} \times Z^*_{(\text{Criteria})}$.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34
C11	0.05	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.07	0.07	0.065	0.06
C12	0.06	0.05	0.07	0.07	0.06	0.07	0.07	0.07	0.06	0.07	0.07	0.066	0.07
C13	0.06	0.06	0.05	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.067	0.06
C14	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.069	0.07
C15	0.07	0.07	0.07	0.07	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.076	0.08
C21	0.09	0.09	0.09	0.09	0.09	0.07	0.09	0.09	0.09	0.09	0.09	0.09	0.09
C22	0.08	0.08	0.08	0.08	0.08	0.08	0.06	0.08	0.07	0.08	0.08	0.078	0.08
C23	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.07	0.08	0.09	0.09	0.089	0.09
C24	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.07	0.07	0.08	0.08	0.084	0.08
C31	0.09	0.09	0.09	0.09	0.09	0.1	0.09	0.09	0.09	0.07	0.08	0.081	0.08
C32	0.09	0.09	0.1	0.09	0.09	0.09	0.09	0.09	0.1	0.08	0.07	0.088	0.08
C33	0.09	0.08	0.08	0.09	0.08	0.09	0.09	0.09	0.09	0.08	0.08	0.068	0.08
C34	0.08	0.08	0.07	0.08	0.08	0.07	0.08	0.07	0.07	0.07	0.08	0.072	0.06

5. Discussion

To provide further clarity, when evaluating the criteria, the outcomes acquired from surveys employing pairwise comparisons enabled the calculation of the all-inclusive.

In the context of dimensions, initially, relying on consensus outcomes derived from 12 distinct focus groups, the comprehensive average matrix $Z_{(\text{Dimension})}$ could be constructed. Subsequently, the percentage of error gap was utilized to assess the data instrument's reliability. Consequently, the total average matrix $Z_{(\text{Dimension})}$ was reconfigured once more $(n-1)$ relative to the quantity of focus groups. In this instance, the number of focus groups stood at $(n-1) = 11$. To establish both direct and indirect influences, a preliminary pre-normalized technique was deemed necessary to proceed. Following the pre-normalization of the initial direct matrix, the all-inclusive Total relational matrix for $Z_{(\text{Dimension})}$ can be illustrated **Table 9**.

The value was employed to denote the summation of the elements in the row of the matrix $Z_{(\text{Dimension})}$. Conversely, indicated the summation of the elements in the column of the matrix $Z_{(\text{Criteria})}$, *R*(row) + *C*(Column) reveals the extent of influence exerted and received. In simpler terms, *R*(row) + *C*(Column) indicates the level of significant control employed when addressing the issue or goal at hand. Similarly, if the difference *R*(row) − *C*(Column) is positively oriented, it signifies that factor i is likely to impact other factors. Conversely, if *R*(row) − *C*(Column) is negatively oriented, it indicates that factor *i* is influenced by other factors. Thus, the interconnectedness of cause and effect within $Z_{(\text{Dimension})}$ is illustrated in **Figure 9**. The subsequent outcomes derived from the analytical DANP model findings are presented in **Table 10**.

Dimensions impact relationship: The conclusions drawn from the relationship matrix highlight three valid dimensions, as depicted in **Figure 9**. Because the matrix contains no null values, it portrays a dynamic relationship within the context of a specific country. Experts posit that the dimension "Resource Reformation" exhibits the most substantial *R*(row) − *C*(Column) value (0.168291); this positive figure signifies a potent influence on other dimensions. Conversely, in terms of significance, "Supply Chain Vulnerability" displays a markedly low *R*(row) − *C*(Column) value (−0.20759); consequently, it remains susceptible to additional influences. As a result, the priority for improvement can be drawn from "Resource Reformation," given its heightened importance. Meanwhile, "Supply Chain Vulnerability" corresponds to a lower priority for subsequent enhancements.

Impact relationship of criteria under the dimension SCV Dimension): The extent of correlation exhibited by "Supply Chain Structure" reveals the most elevated positive *R*(row) − *C*(Column) value (1.26), underscoring its potent impact on other criteria. Conversely, "Supply Chain Security" boasts a notably minimal *R*(row) – *C*(Column) value (−0.33) concerning the criteria, rendering it susceptible to external influence.

Impact relationship of criteria under the dimension Resource Reformation Dimension): In the case of the Resource reformation, Reconfigure Resource has emerged as the highest positive value of *R*(row) − *C*(Column) (0.77), demonstrating the strong influential significance on other criteria, while Realigning Resource shows very low R(row) − C(Column) (−1.18), indicating that it is susceptible to influence. Therefore, the improvement priorities can be ordered from Reconfigure Resource as the highest priority to improve while Realigning Resource as a low priority for further improvement.

Impact relationship of criteria under the dimension SCR Dimension): "Quick Response" registers the most elevated positive R(row) − C(Column) value (0.44), vividly depicting its robust and influential importance on other criteria. Conversely, "Cope with SC Disruption" records a notably low R(row) − C(Column) value (−0.44), indicating its vulnerability to external influence. Hence, with regards to the extent of net interconnection, the hierarchy for enhancement priorities can be established, with "Quick Response" holding the utmost priority for refinement, while "Cope with SC Disruption" is of lower priority for subsequent enhancement. Certain pre-normalized techniques necessitated progression to subsequent stages. Consequently, the normalized preliminary direct relationship $Z^{\alpha}_{(\text{Dimension})}$, as depicted in as shown in **Table 11**.

Table 14. Weighted super matrix *Z**.

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C31	C32	C33	C34
C11	0.042	0.054	0.051	0.053	0.054	0.064	0.061	0.06	0.062	0.071	0.071	0.068	0.067
C12	0.054	0.044	0.057	0.056	0.053	0.069	0.063	0.07	0.062	0.07	0.072	0.069	0.072
C13	0.051	0.047	0.039	0.046	0.047	0.06	0.064	0.06	0.061	0.065	0.062	0.071	0.065
C14	0.056	0.058	0.055	0.046	0.055	0.067	0.072	0.07	0.077	0.075	0.074	0.073	0.077
C15	0.058	0.058	0.058	0.059	0.051	0.077	0.076	0.08	0.075	0.081	0.083	0.08	0.081
C21	0.094	0.091	0.091	0.093	0.095	0.054	0.065	0.07	0.067	0.096	0.096	0.098	0.098
C22	0.086	0.085	0.085	0.085	0.083	0.059	0.047	0.06	0.055	0.086	0.086	0.084	0.084
C23	0.096	0.097	0.097	0.099	0.094	0.065	0.066	0.05	0.064	0.097	0.098	0.097	0.096
C24	0.087	0.089	0.088	0.084	0.089	0.058	0.058	0.06	0.05	0.089	0.089	0.091	0.091
C31	0.099	0.103	0.101	0.098	0.099	0.091	0.09	0.09	0.087	0.059	0.067	0.067	0.071
C32	0.1	0.1	0.107	0.1	0.102	0.09	0.088	0.09	0.091	0.068	0.059	0.074	0.07
C33	0.094	0.092	0.09	0.094	0.093	0.082	0.083	0.08	0.083	0.067	0.067	0.056	0.066
C34	0.086	0.084	0.081	0.086	0.085	0.068	0.072	0.07	0.07	0.062	0.065	0.06	0.049

The subsequent step involves employing the DANP methodologies to determine the relative influence weights, followed by the application of the ANP procedure. The connection between the dimensions and criteria can be elucidated through the unweighted super matrix. However, to simultaneously evaluate the impact of all criteria and dimensions, it becomes imperative to establish the weighted super matrix, within which constraints can be incorporated to compute the overarching weighted matrix encompassing all dimensions and criteria. Concerning the unweighted super matrix, the initial process entails normalizing the total influential matrices for each dimension before transposing them to function as an unweighted matrix. Conversely, a comparable sequence of actions will be executed for the criteria matrix. Finally, to establish the weighted super matrix, the transposition of the normalized sub-criteria matrix is multiplied by the normalized criteria matrix. $G^* = Z_D^{\propto} \times (Z_c^{\propto})$ certain pre-normalized techniques necessitate subsequent procedural stages. Thus, the normalized preliminary direct relationship matrices $Z_{(Dimension)}$ and $Z_{(Criteria)}$ are to be generated. Are shown in **Tables 12–14**.

As depicted in **Table 15**, Overall Local and global weights of criteria related the dimension of Resource Reformation (RR) demonstrates the most substantial weight of 0.31306, consequently being identified as the most critical aspect. In contrast, Supply Chain Resilience (SCR) emerges as the least pivotal dimension, warranting the lowest priority for enhancement due to its minimal weight (0.30856). Therefore, if the strategic objective of decision-makers is to elevate the preparedness significance within manufacturing functions, the top priority for improvement should be the Resource Reformation, followed by SCV and SCR.

Table 15. Overall Local and global weights of criteria related.

Dimension $Z_{(Dimension)}$	Criteria $Z_{(Criteria)}$	Dimension		Criterion	
		Weight	Weight Rank	Weight	Weight Rank
SCV	SCE	0.30879	2	0.050011	13
	SCC			0.0637445	11
	SCS			0.0601017	12
	SCI			0.0665137	10
	SCSE			0.0684224	9
RR	RER	0.31306	1	0.07183759	7
	RCR			0.07842701	4
	RSR			0.08577999	1
	RWR			0.07701332	5
SCR	CSCD	0.30856	3	0.07118313	8
	ASCD			0.08166336	2
	QRSCD			0.08075901	3
	SASCD			0.07495971	6

6. Limitations with practical implications

In pragmatic terms, this study enriches the existing knowledge base by introducing a methodological framework that offers structured guidelines for organizing criteria aimed at reconfiguring supply chains. These guidelines span from evaluating the readiness of supply chain vulnerability to bolstering a firm's capacity to attain supply chain resilience, empowering it to adeptly manage diverse disruptions within the supply chain. Firms with a significant focus on supply chains typically glean insights from previous disruptions and stay watchful of diverse anomalies, including environmental catastrophes, political instability, and economic volatility. According to our research model, building resilience entails firms adeptly adjusting their resources to counter disruptions, especially in developing nations such as Pakistan.

Amid high-impact disruptions, major corporations navigate a journey towards resilience guided by the S-O-R theoretical framework. This process entails evaluating their performance throughout the supply chain. Merely possessing an orientation towards supply chain disruptions and resources is inadequate. The full interrelation of resource reconfiguration between factors driving preparedness for supply chain vulnerability and a firm's ability towards supply chain resilience is crucial. While having resources is important for resilience, they alone cannot guarantee it.

Obtaining essential resources and eliminating less crucial ones is vital for a company's ability to withstand disruptions. Firms focused on supply chain disruptions actively develop and revise resources to promptly detect and address supply chain disruptions. The research emphasized the essential criteria for reforming valuable resources, considering firms' readiness for supply chain vulnerability. It is imperative for firms to discard less important resources to enhance resilience to disruptions. Supply chain disruption-oriented firms actively develop and update resources to promptly identify and respond to disruptions in the supply chain.

Beyond the realm of large-scale manufacturing, this study also aids in bolstering the understanding of supply chain disruption within the broader manufacturing sector of developing nations like Pakistan. This serves as a mechanism to augment value and bolster the overall surplus within the supply chain amidst uncertain conditions. Consequently, policymakers gain awareness of significant vulnerabilities within the supply chain.

Besides addressing the supply chain, this model also facilitates the creation of a novel network model that incorporates organizational-specific elements while taking into account all aspects of large-scale manufacturing. To begin with, this study deepens comprehension of how multicriteria decision-making promotes the exploration of diverse criteria for readiness against supply chain vulnerability within the large-scale manufacturing sector in developing nations. Additionally, this research study will aid in comprehending specific facets of firm resource restructuring, which act as pertinent factors influencing the firm's ability to withstand disruptions.

7. Conclusion

Thus, in this study, the MCDM evaluation technique was applied to determine the effective influence of factors that are significant for vulnerability preparedness across public sector manufacturing firms. From **Table 15**, Resource Reformation (RR) had the greatest impact on other dimensions, while the Supply chain resilience (SCR) had the smallest impact on another dimension. It means that resource reformation (RR) (0.31306) was considered as the most important dimension followed by Supply chain vulnerability (SCV) (0.30879), Supply chain resilience (SCR) (0.30856). This infers that public sector manufacturing firms, it is essential to understand whether public sector firms have the significant ability to reconfigure the resource with accordance to disruption. In terms of Supply chain resilience (SCR), Supply chain vulnerability (SCV) is significant among developing economies usually their impact more effective as combine influence as compared to individual factor. Among the criteria positive resource restructure (0.08577999) was the most significant; followed by adaption towards SC disruption (0.08166336), Quick Response with SC (0.08075901), resource realigned (0.07842701) were second, third and fourth most significant criteria that influence the supply chain preparedness towards the disruption. This infers positive value of resource restructure public sector firms have the significant ability to map their resources according to magnitude of disruption for instance firm need to analyze the under and over utilization of resources.

Author contributions: Conceptualization, ZA and SS; methodology, ZA, SS and AV; software, ZA; validation, AV, SS, TH and YY; formal analysis, SS; investigation, ZA and YY; resources, AV; data curation, YY; writing—original draft preparation, ZA; TH writing—review and editing, ZA and TH; visualization, SS; supervision, ZA; project administration, ZA; funding acquisition, AV. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The authors offer special gratitude to INTI International University for the opportunity to conduct research and publish the research work. In particular, the authors would like to thank INTI International University for funding the publication of this research work. Also, we extend our heartfelt gratitude to all research participants for their valuable contributions, which have been integral to the success of this study.

Conflict of interest: The authors declare no conflict of interest.

References

Abdel-Basset, M., & Mohamed, R. (2020). A novel plithogenic TOPSIS- CRITIC model for sustainable supply chain risk management. Journal of Cleaner Production, 247, 119586. https://doi.org/10.1016/j.jclepro.2019.119586

Alexander, A., Pascucci, S., & Charnley, F. (2023). Handbook of the Circular Economy: Transitions and Transformation. De Gruyter.

Al-Shboul, M. d. A., & Alsmairat, M. A. K. (2023). Enabling supply chain efficacy through SC risk mitigation and absorptive capacity: an empirical investigation in manufacturing firms in the Middle East region—a moderated-mediated model. Supply Chain Management, 28(5), 909-922.

Alsmairat, M. A. K., Mushtaha, A. S., & Hammad, M. S. A. (2023). Understanding the relationship between supply chain risk and lean operations performance|understanding the relationship between supply chain risk and lean operations performance (Polish). Polish Journal of Management Studies, 27(1), 7–25.

Aman, S., & Seuring, S. (2023). Analysing developing countries approaches of supply chain resilience to COVID-19. International Journal of Logistics Management, 34(4), 909-934.

Ambulkar, S., Blackhurst, J., & Grawe, S. (2015). Firm's resilience to supply chain disruptions: Scale development and empirical examination. Journal of Operations Management, 34(1), 111-122.

Bak, O. (2018). Supply Chain Risk Management Research Agenda: From Literature Review to a Call for Future Research Directions. Business Process Management Journal, 24(2), 567–588.

Benjamin, T., Mark, S., & Jerry, B. (2017). Supply chain resilience in a developing country context: a case study on the interconnectedness of threats, strategies and outcomes. Supply Chain Management: An International Journal, 22(6), 486-505.

Bhattacharya, L., Chatterjee, A., & Chatterjee, D. (2023). Critical Enablers that Mitigate Supply Chain Disruption: A Perspective from Indian MSMEs. Management and Labour Studies, 48(1), 42–63.

Biringer, B., Vugrin, E., & Warren, D. (2013). Critical Infrastructure System Security and Resiliency. CRC Press.

Blackhurst, J., Dunn, K., & Craighead, C. W. (2011). An empirically derived framework of global supply resiliency. Journal of Business logistics, 32, 374–391.

Bode, C., & Wagner, S. M. (2015). Structural drivers of upstream supply chain complexity and the frequency of supply chain disruptions. Journal of Operations Management, 36(1), 215–228. https://doi.org/10.1016/j.jom.2014.12.004

Bruckler, M., Wietschel, L., Messmann, L., et al. (2024). Review of metrics to assess resilience capacities and actions for supply chain resilience. Computers & Industrial Engineering.

Bygballe, L., Dubois, A., & Jahre, M. (2023). The importance of resource interaction in strategies for managing supply chain disruptions Journal of Business Research, 154, 113333.

Cardoso, B. d. F. O., Fontainha, T. C., & Leiras, A. (2023). Looking back and forward to disaster readiness of supply chains: a systematic literature review. International Journal of Logistics: Research and Applications.

Chopra, S., & ManMohan, S. S. (2014). Reducing the Risk of Supply Chain Disruptions. MIT Sloan Management Review, 55, 73–80.

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. https://doi.org/10.1108/scm-12-2015-0463

Chowdhury, M. M. H., & Quaddus, M. (2017). Supply chain resilience: conceptualization and scale development using dynamic capability theory. International Journal of Production Economics, 188, 185-204.

Dolgui, A., & Ivanov, D. (2021). Ripple Effect and Supply Chain Disruption Management: New Trends and Research Directions. International Journal of Production Research, 59(1), 102–109.

Dubey, R., Gunasekaran, A., Bryde, D. J., et al. (2020). Blockchain Technology for Enhancing Swift-Trust, Collaboration and Resilience within Humanitarian Supply Chain Setting. International Journal of Production Research, 58(11), 3381–3398.

El Baz, J., & Ruel, S. (2021). Can supply chain risk management practices mitigate the disruption impacts on supply chains' resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era. International Journal of Production Economics, 233, 107972. https://doi.org/10.1016/j.ijpe.2020.107972

Farrell, P., A. M. Thow, J. T. Wate, N. et al. (2020). COVID-19 and Pacific Food System Resilience: Opportunities to Build a Robust Response. Food Security, 12(4), 783–791.

Foundation, W. M. (2022). The 2022 World Manufacturing Report: Redesigning Supply Chains in the New Era of Manufacturing. Available online: https://worldmanufacturing.org/wp-content/uploads/17/6-2022_World-Manufacturing-Report_E-Book.pdf (accessed on 2 June 2023).

Garlick, C., McMillan, M., Peterson, R., et al. (2020). Case Study Review of the Effects of COVID-19 on the Supply Chain of Manufacturing Companies in California. In: Proceedings of the international conference on industrial engineering and operations management.

Gaudenzi, B., Pellegrino, R., & Confente, I. (2023). Achieving supply chain resilience in an era of disruptions: a configuration approach of capacities and strategies. Supply Chain Management, 28(7), 97-111.

Ghasemaghaei, M. (2019). Does data analytics use improve firm decision making quality? The role of knowledge sharing and data analytics competency. Decision Support Systems, 120(2), 14-24.

Gligor, D., Feizabadi, J., Russo, I., et al. (2020). The triple-a supply chain and strategic resources: developing competitive advantage. International Journal of Physical Distribution & Logistics Management, 50(2), 159-190.

Gölgeci, & Kuivalainen. (2020). Does social capital matter for supply chain resilience? The role of absorptive capacity and marketing-supply chain management alignment. Industrial Marketing Management, 84, 63-74.

Gracia, O., Timotius, S., Teofilus., et al. (2020). Adaptive Supply Chain Management under Severe Supply Chain Disruption: Evidence from Indonesia. Journal of Distribution Science, 18, 91-103.

H¨agele, S., Grosse, E. H., & Ivanov, D. (2023). Supply chain resilience: a tertiary study. International Journal integrated Supply Management, 16(1), 52–81.

Hsu, C. H., Chang, A. Y., Zhang, T. Y., et al. (2021). Deploying resilience enablers to mitigate risks in sustainable fashion supply chains. Sustainability, 13(5), 2943.

Idris, S., Musnadi, S., Djalil, M. A., et al. (2023). The effect of supply chain integration capability and green supply chain management (GCSM) on manufacturing industry operational performance. Uncertain Supply Chain Management, 11(3), 933–940.

Ivanov, D., Sokolov, B., & Dolgui, A. (2014). The ripple effect in supply chains: trade-off 'efficiency-flexibility resilience' in disruption management. International Journal of Production Research, 52(7), 2154-2172.

Kähkönen, A. K., Evangelista, P., Hallikas, J., et al. (2023). COVID-19 as a trigger for dynamic capability development and supply chain resilience improvement. International Journal of Production Research, 61(8), 2696–2715. https://doi.org/10.1080/00207543.2021.2009588

Kamalahmadi, M., & Parast, M. M. (2016). A review of the literature on the principles of enterprise and supply chain resilience: Major findings and directions for future research. International Journal of Production Economics, 171(1), 116–133.

Khilwani, N., Tiwari, M. K., & Sabuncuoglu, I. (2011). Hybrid Petri-nets for modelling and performance evaluation of supply chains. International Journal of Production Research, 49(15), 4627–4656. https://doi.org/10.1080/00207543.2010.497173

Khokhar, M., Iqbal, W., Hou, Y., et al. (2020). Assessing Supply Chain Performance from the Perspective of Pakistan's Manufacturing Industry Through Social Sustainability. Processes, 8(9), 1064.

Kim, M. J., Lee, C. K., & Jung, T. (2019). Exploring consumer behavior in virtual reality tourism using an extended stimulus-organism-response model. Journal of Travel Research.

Knut Alicke, Edward, B., Tacy, F., et al. (2022). Taking the pulse of shifting supply chains. Available online: https://www.mckinsey.com/capabilities/operations/our-insights/taking-the-pulse-of-shifting-supply-chains (accessed on 2 June 2023).

Kumar, G., R. K. Singh, R., Jain, et al. (2020). Analysis of Demand Risks for the Indian Automotive Sector in Globally Competitive Environment. International Journal of Organizational Analysis.

Kurdi, B. A., Alzoubi, H. M., Alshurideh, M. T., et al. (2023). Impact of supply chain 4.0 and supply chain risk on organizational performance: An empirical evidence from the UAE food manufacturing industry. Uncertain Supply Chain Management, 11(1), 111-118

Lee, H. Y., Seo, Y. J., & Dinwoodie, J. (2016). Supply chain integration and logistics performance: the role of supply chain dynamism. The International Journal of Logistics Management, 27(3), 668–685. https://doi.org/10.1108/ijlm-06-2015-0100

Mehrabian, Albert, & Russell., J. A. (1974). An Approach to Environmental Psychology. The MIT Press.

Min, H. (2019). Blockchain Technology for Enhancing Supply Chain Resilience. Business Horizons, 62(1), 35–45.

Mishra, R., R. K. Singh, & N. P. Rana. (2022). Developing Environmental Collaboration among Supply Chain Partners for Sustainable Consumption & Production: Insights from an Auto Sector Supply Chain. Journal of Cleaner Production, 338, 130619. https://doi.org/10.1016/j.jclepro.2022.130619

Munir, M., Jajja, M. S. S., Chatha, K. A., et al. (2020). Supply chain risk management and operational performance: The enabling role of supply chain integration. International Journal of Production Economics, 227, 107667. https://doi.org/10.1016/j.ijpe.2020.107667

Nelson, D., & Ricardo, V. (2023). Literature Review of Accreditation Systems in Higher Education. Education Sciences, 13. https://doi.org/10.3390/educsci13060582

Nguyen, S., Chen, P. S. L., & Du, Y. (2023). A methodological framework for quantitative risk analysis in container shipping operations. Maritime Business Review, 8(2), 139-155.

Oger, R., Lauras, M., Montreuil, B., et al. (2020). A decision support system for strategic supply chain capacity planning under uncertainty: conceptual framework and experiment. Enterprise Information Systems, 16(5). https://doi.org/10.1080/17517575.2020.1793390

Paksoy, T., Çalik, A. A. Y., & Huber, S. (2019). Risk Management in Lean & Green Supply Chain: A Novel Fuzzy Linguistic Risk Assessment Approach. Springer.

Pandey, S., Singh, R. K., & Gunasekaran, A. (2021). Supply chain risks in Industry 4.0 environment: review and analysis framework. Production Planning & Control, 34(13), 1275–1302. https://doi.org/10.1080/09537287.2021.2005173

Petersen, K. J., Ragatz, G. L., & Monczka, R. M. (2005). An examination of collaborative planning effectiveness and supply chain performance. Journal of Supply Chain Management, 41(2), 14–25.

Pettit, T. J., Croxton, K. L., & J. Fiksel. (2019). The Evolution of Resilience in Supply Chain Management: A Retrospective on Ensuring Supply Chain Resilience. Journal of Business logistics, 40, 56–65.

Pettit, T. J., Fiksel, J., & Croxton, K. L. (2010). Ensuring supply chain resilience: Development of a conceptual framework. Journal of Business logistics, 21(1), 1-21.

Piprani, A. Z., Jaafar, N. I., Ali, S. M., et al. (2022). Multi-dimensional supply chain flexibility and supply chain resilience: the role of supply chain risks exposure. Operations Management Research, 15, 307–325.

Rahman, T., Paul, S. K., Shukla, N., et al. (2022). Supply chain resilience initiatives and strategies: A systematic review. Computers & Industrial Engineering, 170, 108317.

Rajesh, R. (2019). Fuzzy Approach to Analyzing the Level of Resilience in Manufacturing Supply Chains. Sustainable Production and Consumption, 18, 224–236.

Rajesh, R. (2023). An introduction to grey causal modelling (GCM): applications to manufacturing, supply chains, resilience, and sustainability. Artificial Intelligence Review, 56, 6267–6293.

Rameshwar, D., David J., B., Yogesh K., D., et al. (2023). Dynamic digital capabilities and supply chain resilience: The role of government effectiveness. International Journal of Production Economics, 258.

Rezaei, A., Aghsami, A., & Rabbani, M. (2021). Supplier selection and order allocation model with disruption and environmental risks in centralized supply chain. International Journal of Systems Assurance Engineering and Management.

Sawik, T. (2021). A rough cut Cybersecurity Investment Using Portfolio of Security Controls with Maximum Cybersecurity Value. International Journal of Production Research, 1–17.

Sharma, S. K., Routroy, S., Singh, R. K., et al. (2022). Analysis of supply chain vulnerability factors in manufacturing enterprises:

a fuzzy DEMATEL approach. International Journal of Logistics Research and Applications.

Sharma, S. K., Srivastava, P. R., Kumar, A., et al. (2023). Supply chain vulnerability assessment for manufacturing industry. Annals of Operations Research, 326, 653–683.

Sheffi, Y. (2020). The new (ab) normal: Reshaping business and supply chain strategy beyond Covid-19. MIT CTL Media.

Shih, W. (2020). Is it Time to Rethink Globalized Supply Chains. MIT Sloan Management Review, 61(4), 1–3.

Shin, S., Lee, S., Judi, D. R., et al. (2018). A systematic review of quantitative resilience measures for water infrastructure systems. Water (Switzerland), 10, 1–25.

Silva, M. E., & Figueiredo, M. D. (2020). Practicing sustainability for responsible business in supply chains. Journal of Cleaner Production, 251.

Stecke, K. E., & Kumar, S. (2009). Sources of Supply Chain Disruptions, Factors That Breed Vulnerability, and Mitigating Strategies. Journal of Marketing Channels, 16(3).

Stephens, A. M., Kang, M., & Robb, C. A. (2022). Linking Supply Chain Disruption Orientation to Supply Chain Resilience and Market Performance with the Stimulus-Organism-Response Model. Journal of Risk and Financial Management, 15(5), 227. https://doi.org/10.3390/jrfm15050227

Sturm, S., Hohenstein, N. O., Birkel, H., et al. (2021). Empirical research on the relationships between demand-and supply-side risk management practices and their impact on business performance. Supply Chain Management: An International Journal, 27(6), 742-761.

Tuncel, G., & Alpan, G. (2010). Risk assessment and management for supply chain networks: A case study. Computers in industry, 61(3), 250–259.

Turner, N., Aitken, J., & Bozarth, C. (2018). A framework for understanding managerial responses to supply chain complexity. International Journal of Operations & Production Management, 38(6), 1433–1466. https://doi.org/10.1108/ijopm-01-2017-0062

Umunnakwe, A., Huang, H., Oikonomou, K., et al. (2021). Quantitative analysis of power systems resilience: Standardization, categorizations, and challenges. Renewable and Sustainable Energy Reviews, 149, 111252. https://doi.org/10.1016/j.rser.2021.111252

Van Hoyweghen, K., Fabry, A., Feyaerts, H., et al. (2021). Resilience of global and local value chains to the Covid-19 pandemic: Survey evidence from vegetable value chains in Senegal. Agricultural Economics, 52(3), 423–440. https://doi.org/10.1111/agec.12627

Waller, M., Williams, J. E., & LeMay, S. A. (2008). Supply Chain Security: An Overview and Research Agenda. The International Journal of Logistics Management, 19(2), 254–281.

WEF. (2020). Helping companies avoid disruptions to global supply chains. Available online: https://www.weforum.org/projects/reshaping-global-value (accessed on 2 June 2023).

Wei, H. L., & Wang, E. (2010). The strategic value of supply chain visibility: increasing the ability to reconfigure. European Journal of Information Systems, 19, 238–249.

Wieland, A., & Durach, C. F. (2021). Two perspectives on supply chain resilience. Journal of Business logistics, 42(3), 315-322.

Xu, J., Zhuang, J., & Liu, Z. (2015). Modeling and mitigating the effects of supply chain disruption in a defender-attacker game. Annals of Operations Research, 236(1), 255–270. https://doi.org/10.1007/s10479-015-1810-z

Xu, L., Deng, Y., & Mancl, K. (2019). Environmental disaster risk reduction-oriented centralized treatment of hazardous wastes: A novel approach for production-distribution decision optimization in China. International Journal of Disaster Risk Reduction, 40, 101263. https://doi.org/10.1016/j.ijdrr.2019.101263

Yan, X., Li, J., Sun, Y., et al. (2023). Supply Chain Resilience Enhancement Strategies in the Context of Supply Disruptions, Demand Surges, and Time Sensitivity. Fundamental Research.

Yang, J., Xie, H., Yu, G., et al. (2021). Antecedents and consequences of supply chain risk management capabilities: an investigation in the post-coronavirus crisis. International Journal of Production Research, 59(5), 1573–1585. https://doi.org/10.1080/00207543.2020.1856958

Yontar, E. (2023). Critical success factor analysis of blockchain technology in agri-food supply chain management: A circular economy perspective. Journal of Environmental Management, 330, 117173.

Yosef, F. A., Jum'a, L., & Alatoom, M. (2023). Identifying and Categorizing Sustainable Supply Chain Practices Based on Triple Bottom Line Dimensions: Evaluation of Practice Implementation in the Cement Industry. Sustainability, 15(9), 7323.

Zeng, B., & Yen, B. P. C. (2017). Rethinking the role of partnerships in global supply chains: A risk-based perspective.

International Journal of Production Economics, 185, 52–62. https://doi.org/10.1016/j.ijpe.2016.12.004
Zhang, M., Tse, Y. K., & Doherty, B. (2018). Sustainable supply chain management: Confirmation of a higher-order model. Resources, Conservation and Recycling, 128, 206-221.