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ORIGINAL RESEARCH

Analyzing the Inter-relationships of Business Recovery Challenges in the Manufacturing Industry: Implications for Post-pandemic Supply Chain Resilience

Ashish Dwivedi[1] · Shefali Srivastava[2] · Dindayal Agrawal[3] · Ajay Jha[4] · Sanjoy Kumar Paul[5]

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Abstract *The COVID-19 pandemic brought about a rapid change in the global business environment, leading to increased risks of supply and demand disruptions. As society and the industry continue to acclimate to the new normal, the contributions of the manufacturing industry are critical in the recovery process. However, the existing literature lacks a framework to analyze the manufacturing sector's challenges during the recovery to enhance supply chain resilience (SCR). To address this gap, this study develops a framework for business recovery, especially in the manufacturing sector. A broad literature examination and expert survey were conducted to identify the critical potential business recovery challenges. Further, the interplay of business recovery challenges was analyzed using mixed methodologies such as total interpretive structure model and the cross-impact matrix multiplication applied to classification (MICMAC) to foster a framework that can assist the manufacturing industry in improving SCR. The study found that challenges like 'lack of flexible policies for handling disruptions' and 'lack of management support toward building resilience' have the highest driving power impeding business recovery. Other challenges, such as 'lack of reconfiguring production lines,' 'lack of product competencies to meet disturbances,' and 'less adoption of robust technologies' are also identified as major challenges. The implications of the study offer valuable insights into global manufacturing industries. It also has significant propositions for the Pacific region. The Pacific region faces unique challenges, including geographic isolation, resource dependency, diverse economies, climate vulnerabilities, and complex trade relationships. The suggested framework's adaptability and applicability to these regional characteristics enable businesses and policymakers in the Pacific to better understand and address the specific dynamics of post-pandemic recovery, ultimately contributing to enhanced SCR tailored to the region's needs. The study enriches the existing SCR literature by analyzing inter-relationships between business recovery challenges in the manufacturing industry's post-pandemic context.*

Keywords Business recovery challenges · Flexible policies · Manufacturing industry · Supply chain resilience

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

Ashish Dwivedi
ashish0852@gmail.com

Shefali Srivastava
shefali.srivastava009@gmail.com

Dindayal Agrawal
ddagrawal123@gmail.com

Ajay Jha
ajay.jha@jaipuria.ac.in

1 Jindal Global Business School, O.P. Jindal Global University, Sonipat, India

2 Operations and Decision Sciences, Christ University, Bangalore, India

3 Institute of Management Technology, Ghaziabad, India

4 Decision Sciences, Jaipuria Institute of Management, Lucknow, India

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

Introduction

In the early 2020s, the globalized world faced significant disruptions due to the COVID-19 pandemic (Hasan et al., 2023; Ikram & Sayagh, 2023). It caused lockdowns of public utilities and restricted movement across boundaries, resulting in disruptions to global economic activities. The International Monetary Fund (IMF) reported a 4.4% reduction in global economic growth in 2020 alone (PBS, 2020). Although 2021 and 2022 were considered the recovery phase of the pandemic due to the development of vaccines and social adjustments, there were other incidents, such as the Russia–Ukraine war, energy crises, and financial institution failures that derailed the economic recovery process and pushed the world toward a recessionary phase (Allam et al. 2022). The year 2023 is also expected to be marred by high inflation rates, low economic growth, high debt, and high fragmentation, affecting business growth and human living standards. Barring a few developed economies like Australia, China, South Korea, and Japan, the region is highly impacted due to reliance on trade, transport, foreign accruals and tourism (Palit & Bhogal, 2022). The small and medium sector also needs consolidation to avoid reliance on imports from trading partners. Business organizations of the region must carefully anticipate the changing global dynamics, their capabilities and reliance on regional and western partners, and plan accordingly to survive and sustain. This cautious planning may include industrial partnering, strategic sourcing, infrastructure development, optimizing operational expenses (such as hiring and firing workers), diversified manufacturing and distribution networks, manufacturing skill development, and data-driven demand management systems (Tomlin & Wang, 2011). Adopting advanced analytics, monitoring tools, and other digital technologies can help track and manage the performance of a firm's suppliers and detect potential logistics risks (Ivanov & Dolgui, 2021). Governance bodies and international organizations must streamline global geo-political adaptation, relieving geo-political fissures and facilitating cross-border cooperation (Grundy-Warr, 2022).

In the post-pandemic era, as society and industry continue to embrace the 'new normal,' the manufacturing sector performs a crucial function in the recovery process (Telukdarie et al., 2020). It forms the backbone of any economy, providing modern tools and techniques to support the primary sector and driving growth in the tertiary sector. However, the manufacturing sector is currently facing constant liquidity and profitability challenges due to pandemic vulnerabilities, which have been compounded by economic shocks (Didier et al., 2021). Supplier defaults and poor revenues have created fright in the industry, leading to market inconsistencies and inaccurate supply–demand configurations (Jauhar et al., 2023). The decline in manufacturing influences the unemployment and poverty status of the region. To recover from distorted supply chain patterns, the manufacturing sector requires a strategic approach called Business Process Innovation (Anand et al., 2013), which aims to perform manufacturing operations at high speed and agility, prioritizing business continuity with risk management, focusing on information technology applications, and stakeholder confidence (Butt, 2020).

While global manufacturing has been a moderate resurgence since the post-pandemic lockdowns, supply chain disruptions, recessionary pressures, and geo-political tussles pose multiple challenges (Wenzel et al., 2020). Addressing rising labor and material costs, industrial finance and supply chain disruptions, developing responsive processes, and developing tools to manufacture in other areas than China require a lot of effort. The adoption of digital technologies can largely address bottlenecks in global manufacturing operations and supply chain coordination, and the industry is earnestly adopting the digital transition (Acioli et al., 2021). Investing in digital technology can help capture data to assess targeted vs actual performance in terms of energy consumption, resource utilization and recycling, carbon footprint, and societal impact (Fernando & Hor, 2017). Designing for efficiency and rigorous supplier management are other aspects of this transformation and recovery process.

However, much more needs to be done to ensure that the regional partners and vendors that feed resources and data into the business systems follow the same sustainability guidelines. Data visibility and analytics can yield results only when the manufacturer has built agility into its operations, allowing new strategies to be quickly implemented. Agility is a challenging measure for small and medium enterprises (SMEs), which have been particularly disturbed by the pandemic due to their limited resources and customer base (Juergensen et al., 2020). Reconfiguring the production activities of organizations is required to satisfy the scarcity of overseas-produced items from the perspective of customer-base changes (Liu & Yang, 2021). Manufacturers diversify their supply base and optimize their stocks by near-shoring or domestic sourcing to mitigate risks and gain better control over transaction costs with economies of scale (Kapoor et al., 2021). Another innovation to overcome market loss is servitization, where a manufacturing firm transitions from product-centric to service-centric business logic (Eloranta et al., 2021).

Streamlining financial requirements in these challenging times is another critical consideration in the industry recovery process. Integrating the financial system into supply chain operations through data visibility and analytics can lead to more transparent financial transactions.

Artificial intelligence (AI)-powered forecasting can assist manufacturers in better understanding demand and supply variations early on, allowing for corrective action and optimization of profit margins. The role of the manufacturing sector is critical for economic recovery, making it necessary to understand the new challenges and develop suitable strategies and solutions. To this end, this study proposes to address the subsequent research questions (RQs):

RQ1 What are the business recovery challenges in the manufacturing industry?

RQ2 How can the inter-relationships among business recovery challenges be investigated?

RQ3 In what way can the driving-dependence influence of each business recovery challenge be obtained?

This study aims to accomplish the subsequent research objectives (ROs):

RO1 To develop an integrated framework for analyzing business recovery challenges in the manufacturing industry.

RO2 To provide managerial insights for improving post-pandemic SCR.

Literature Review

This segment is structured into three main components. The first segment presents a literature review on the theme of SCR in manufacturing industries. The second part identifies and discusses the major business recovery challenges faced by manufacturing industries based on the literature. Finally, the research gaps in this area are highlighted.

Studies on SCR in Manufacturing Industries

Creating and sustaining a robust supply chain capable of satisfying requirements even in the expression of substantial disruptions in both supply and demand is vital for the survival of manufacturing companies (Ivanov & Keskin, 2023; Ishak et al., 2023). The literature highlights several studies on resilience, supply chain and the manufacturing industry. Palit and Bhogal (2022) highlight the alternate sourcing strategy to China for SCR initiative. Another major component of manufacturing vulnerability is the SMEs weak share and weak bargaining power in case of uncertainties and support to disasters. The resilience of SMEs demands financial support and diversification to cope with demand shocks and market volatility (Ye & Abe, 2012). Ahmed et al. (2023) conducted a study to assess the AI-based essentials of Industry 5.0 (I5.0) to enhance SCR. The study discovered that real-time tracking and AI intervention of supply chain functionalities are the most prominent tool to enhance SCR. Bianco et al. (2023) studied the consequences of Industry 4.0 (I4.0) implementation in improving SCR during the COVID-19 outbreak. The results from their study indicate that smart manufacturing practices contribute to developing resilience and reducing losses during pandemics.

Similarly, Nakandala et al. (2023) found that operations resilience and incremental innovation act as mediators between I4.0 technologies and SCR. Yin (2023) presented a study to develop a theoretical framework for digital transformation-based SCR. The study discovered six different pathways toward achieving high SCR. Pu et al. (2023) conducted a study to underline the impact of three scopes of SCR on sustainable competitive advantages. The study proposed research hypotheses and a conceptual framework adopting operational vulnerability as an intermediary element. Hemant et al. (2022) directed a study to examine the technological and non-technological enablers in the context of Indian manufacturing industries. Ambrogio et al. (2022) presented a study to inspect the influence of COVID-19 on SCR and the workforce. The study proposed three I4.0-driven solutions that can enhance workforce resilience. Additionally, Chari et al. (2022) explored the contribution of dynamic capabilities theory in enhancing SCR, using empirical analysis to report on the challenges of implementing circular economy practices. Agarwal et al. (2022) presented a study to rank the resilience effectiveness required for an I4.0 manufacturing organization, identifying six capabilities to mitigate barriers to SCR. Furthermore, Rajesh (2021) identified flexible business strategies across different views of the supply chain that contribute to building resilience based on a case study of an electronic manufacturing industry. Belhadi et al. (2021) investigated the effect of the COVID-19 outbreak on the airline and automobile industries through empirical analysis of SCR in manufacturing industries. Similarly, Elhabashy et al. (2021) accompanied a literature review to study resiliency in manufacturing systems in the I4.0 model.

Dev et al. (2021) accomplished simulation analysis to study SCR in handling the ripple effect in the I4.0 paradigm. Rajesh (2017) performed a total interpretive structure model (TISM) to highlight the interactions between technological capabilities considering an electronic manufacturing company. Zineb et al. (2017) performed a quantitative study to analyze SCR, considering the case of the Moroccan manufacturing industry. They found that enhanced flexibility and collaborations improve the resilience of industry supply chains.

Business Recovery Challenges in Manufacturing Industries

During the post-pandemic, manufacturers' greatest challenge is to regain past clients and new markets and maintain positive business relationships. According to a Gartner study, 75% of companies will lose customers who are not a good fit by 2025. AI-enhanced supply chain management can reduce lost sales due to out-of-stock products by 65% (Klappich et al., 2021). Another challenge posed by the current turbulent market environment for the industrial sector is a commitment to sustainability. Resurgent manufacturing requires the adoption of I4.0 and I5.0 technologies, eco-friendly transport facilities, and an optimized logistics network. Operations and information technologies come together to form I4.0 (Verma et al., 2022). Meanwhile, I5.0 calls for the synergistic coexistence of 'man and machine,' otherwise known as robots or cobots (Dwivedi et al., 2023). Workforce training to handle such transitions is another ongoing need. The organizational behavior aspect of industries needs to accommodate flexible workforce management, allowing for both offline and online working environments and assimilating online-trained personnel into organizational operations. Table 1 presents a list of fifteen business recovery challenges that have been identified based on the literature analysis and expert discussion.

Research Gaps

The research that is currently available shows that financial failures, geo-political tensions, and the recession brought on by the pandemic have all had a negative impact on the manufacturing sector. There is an urgent need to revive the sector for better global economic health. The acceptance of digital technologies, the internet, and supply chain risk management strategies have been discussed worldwide as ways to address the manufacturing needs of the world. While there have been studies on supply chain disruption and strategic sourcing in the post-pandemic scenario (Aldrighetti et al., 2021; Ivanov, 2021), manufacturing business recovery in the Pacific context requires attention. Factors related to manufacturing recovery, agile manufacturing, and the role of I4.0 and I5.0 in the manufacturing recovery process have been overlooked (Farooq et al., 2021; Ibn-Mohammed et al., 2021; Remko, 2020). Similarly, there has been a superficial treatment of understanding the associated challenges and factors related to the adoption of digitized tools and process re-engineering in relation to SMEs (Aldrighetti et al., 2021; Younis et al., 2021). Issues such as management commitment, employee competencies, skills, and work reorganization, process redesign, financial inclusivity, and policy interventions require in-depth treatment to develop a holistic framework for manufacturing resurgence. This study aims to satisfy this research gap by identifying and analyzing business recovery challenges in the manufacturing industry while providing insights into their management.

Research Methodology and Data Analysis

The study integrates a mixed-method research design to understand the concept comprehensively. The practical consequence of adopting a mixed-method approach is that the researcher should be proficient in employing research

Table 1 List of business recovery challenges identified from the literature

Code	Name of the business recovery challenge	References
BR1	Poor communication among supply chain stakeholders	Paul et al. (2021), Banerjee et al. (2022)
BR2	Lack of collaboration between stakeholders	Ocicka et al. (2022), Sabahi and Parast, (2020)
BR3	Lack of management support toward building resilience	Paul et al. (2021), Banerjee et al., 2022
BR4	Lack of flexible policies for handling disruptions	Ocicka et al. (2022), Wang et al. (2018), Paul et al. (2015)
BR5	Lack of financial capabilities to handle the disruptions	Chopra et al. (2021), Banerjee et al. (2022)
BR6	Unauthorized subcontracting and raw material sourcing	Rajesh (2018), Clarke and Boersma (2017)
BR7	Lack of real-time data on supply chain operations	Majumdar et al. (2020), Paul et al. (2021)
BR8	Lack of flexibility in the supply chain design	Rajesh (2018), Paul et al. (2021)
BR9	Lack of transparency in supply chains	Sabahi and Parast, (2020), Banerjee et al. (2022)
BR10	Lack of multi-channel purchasing strategies	Monostori and Váncza (2020), Banerjee et al. (2022)
BR11	Lack of ease of supplier geo-relocation	Malik et al. (2021), Ocicka et al. (2022)
BR12	Lack of reconfiguring production lines	Sabahi and Parast, (2020), Chopra et al. (2021)
BR13	Lack of product competencies to meet disturbances	Ishida et al. (2020), Clarke and Boersma (2017)
BR14	Disconnected workflows and processes	Sharma et al. (2022), Majumdar et al. (2020)
BR15	Less adoption of robust technologies	Sabahi and Parast, (2020), Monostori and Váncza (2020)

techniques that encompass qualitative and quantitative methods, as well as statistical skills for data collection and exploration. The advantage of using such an approach lies in mitigating the biases and constraints that may arise from relying solely on one research method (Creswell, 2009). However, it is important to acknowledge that positivism, which underpins the study's framework development, indeed has its strengths, such as its empirical and objective approach. However, it is crucial to recognize that positivism has limitations, particularly in cases where human behaviors, social contexts, and qualitative insights play a significant role in shaping the research outcomes (Denzin & Lincoln, 2011). This study analyzes business recovery challenges in the manufacturing industry, and the multifaceted and context-specific nature of the challenges may not be entirely captured through a solely positivist lens. Therefore, the study embraces a combined-method approach that syndicates quantitative examination with qualitative understandings from experts in the field, thus providing a more holistic understanding of the complex dynamics of the research problem.

The qualitative methods involved conducting an inclusive review of the literature to recognize the business recovery challenges. On the other hand, a survey-based approach was employed for implementing the modified TISM (m-TISM) framework, which constitutes the quantitative methods. It also applies a systems thinking approach to understand the interconnectedness between different recovery challenges in the manufacturing industry and their influence on SCR. This paradigm encourages viewing the manufacturing system and supply chain as a complex, interrelated network.

Questionnaire Design and Data Collection

A systematic questionnaire was developed to explore the business recovery challenges in the manufacturing industry, which were identified in this study. The questionnaire was face-to-face delivered to each respondent to ensure that the desired expert was the defendant and to minimize the chances of ignored emails. The aimed manufacturing industries were positioned in India's National Capital Region. The particulars of the participating experts are postulated in Table 6.

Determining the Inter-relationships Among Business Recovery Challenges

In 1973, Warfield established a computer-assisted process called interpretive structural modeling (ISM) to create interactions between numerous elements resulting from a particular situation, with recommendations from experts determining how the elements interact, making it an interpretive technique (Yadav et al., 2020). However, despite its ability to study various management scenarios through an ordered model description, ISM has several drawbacks (Mathivathanan et al., 2021). To overcome these limitations, an enhanced model called TISM was proposed, which utilizes the interpretive matrix to illustrate how causal reasoning is obtained when evidence is gathered by specialists (Sushil, 2012). TISM highlights the linkages that connect the two items next to the relationship descriptions, thus addressing the limitations of ISM. To further simplify the ISM methodology and advance it, a m-TISM was proposed by Sushil (2017), which expands on TISM's knowledge of inter-relationships, degree of association, and reasoning underlying the inter-relationships. It also requires less number of pair-wise comparisons compared to ISM (Sushil, 2018; Dhir et al., 2021).

The m-TISM methodology has been functional in numerous studies to address complex issues (Dwivedi et al., 2021; Prabhu & Srivastava, 2023; Shekhar & Das, 2023). For example, Dwivedi et al. (2023) utilized m-TISM to examine the interaction between I5.0 and circular supply chains from a sustainable development perspective. Sindhwani et al. (2022) applied m-TISM to analyze resilience in the MSME sector, while Rajan et al. (2021) developed an m-TISM model for cybersecurity management in organizations. Meena et al. (2021) focused on the automotive sector in India, analyzing and modeling factors that accelerate growth in this industry. Dwivedi et al. (2019) also proposed TISM for sustainable manufacturing, using the leather sector as an example. The m-TISM approach involves several fundamental steps.

Step I: Identifying the business recovery challenges in the manufacturing industry

The initial stage of the m-TISM methodology involves identifying the challenges that are pertinent to the situation (Kumar et al., 2018). This study directed a literature review and interviews to examine the business recovery challenges in the manufacturing sector. A total of fifteen challenges were identified and are presented in Table 1.

Step II: Describing the contextual inter-relationships

To develop a framework, it is crucial to establish the appropriate linkages among the recognized potential challenges (Kumar et al., 2019). The contextual relationships between business recovery challenges in the manufacturing industry were inferred.

Step III: Explanation of the inter-relationships

To determine the model's coherence, the inter-relationships among the identified possible challenges are interpreted and presented in Table 7.

Step IV: Pair-wise comparison

As indicated in Table 2, it is possible to ascertain whether an interaction matrix between the challenges exists based on the experts' recommendations.

Step V: Achieving the Reachability Matrix and transitivity check

Table 3 presents the initial reachability matrix (IRM) for the recognized possible difficulties. To create the final reachability matrix (FRM), as displayed in Table 4, the IRM is further examined for transitivity links restructured as 1*. In addition to pair-wise comparison, a transitivity check is also carried out simultaneously.

Step VI: Separating the reachability matrix

The FRM was divided into multiple levels by executing several iterations for each identified challenge, as shown in Table 5.

Step VII: Diagraph development

In Fig. 1, a simplified digraph illustrating transitive inter-relationships is conquered.

Step VIII: Obtaining the m-TISM

The digraph illustrating the relationships between the recognized possible difficulties is transformed into a m-TISM model, as displayed in Fig. 2. The dotted arrow shows the transitive relationship, whereas the bold arrow signifies the direct link.

Data Analysis

This section investigates the data and presents the results and findings.

Developing the IRM

An IRM in m-TISM is produced by replacing 1 and 0 in accordance with a set of guidelines. Table 2 highlights the IRM.

Developing the FRM

As demonstrated in Table 3, the FRM is produced by assimilating the transitivity given by '*.'

Level Partitions

The FRM is adopted to decide the reachability and antecedent set for every potential challenge that has been identified. Until each challenge reaches its appropriate level, the process is repeated. Tables 4 and 5 show the iterations.

Development of Diagraph

A simplified digraph illustrating transitive inter-relationships is presented in Fig. 1.

Inter-relationships Among the Business Recovery Challenges

The m-TISM model reflects inter-relationships among the identified business recovery challenges and is presented in Fig. 2.

Driving-Dependence Impact of each Business Recovery Challenge

MICMAC analysis determines the driving and dependent power of the interconnected challenges and is derived from the FRM (Dwivedi et al., 2023). The challenges are divided into four groups, which are explained as follows.

Table 2 IRM for business recovery challenges

Code	BR1	BR2	BR3	BR4	BR5	BR6	BR7	BR8	BR9	BR10	BR11	BR12	BR13	BR14	BR15
BR1	1	0	0	0	0	1	0	0	0	1	1	1	0	0	0
BR2	1	1	0	0	0	1	1	0	0	1	1	1	1	1	1
BR3	0	0	1	0	1	1	1	1	1	1	0	0	1	1	1
BR4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
BR5	0	0	0	0	1	1	0	1	0	1	1	1	1	1	1
BR6	0	0	0	0	0	1	1	0	0	1	0	1	0	0	1
BR7	0	0	0	0	0	0	1	0	1	1	0	1	1	1	1
BR8	1	0	0	0	0	1	0	1	1	1	1	1	1	1	1
BR9	0	0	0	0	0	1	1	0	1	1	0	1	1	1	1
BR10	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0
BR11	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
BR12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
BR13	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
BR14	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
BR15	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1

Table 3 FRM for business recovery challenges

Code	BR1	BR2	BR3	BR4	BR5	BR6	BR7	BR8	BR9	BR10	BR11	BR12	BR13	BR14	BR15	Dr
BR1	1	0	0	0	0	1	1*	0	1*	1	1	1	1*	1*	1*	10
BR2	1	1	0	0	0	1	1	0	1*	1	1	1	1	1	1	11
BR3	1*	0	1	0	1	1	1	1	1	1	1*	1*	1	1	1	13
BR4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
BR5	1*	0	0	0	1	1	1*	1	1*	1	1	1	1	1	1	12
BR6	1*	0	0	0	0	1	1	0	1*	1	0	1	1*	1*	1	9
BR7	1*	0	0	0	0	1*	1	0	1	1	0	1	1	1	1	9
BR8	1	0	0	0	0	1	1*	1	1	1	1	1	1	1	1	11
BR9	1*	0	0	0	0	1	1	0	1	1	0	1	1	1	1	9
BR10	0	0	0	0	0	1*	1*	0	1	1	0	1	1	1*	1*	8
BR11	1*	0	0	0	0	0	0	0	0	0	1	1*	1*	1	1	6
BR12	1*	0	0	0	0	0	0	0	0	0	0	1	1*	0	1	4
BR13	1*	0	0	0	0	0	0	0	0	0	0	1	1	1	1	5
BR14	1*	0	0	0	0	0	0	0	0	0	0	1	1*	1	1	5
BR15	1	0	0	0	0	1*	0	0	0	1*	1*	1*	1	1*	1	8
De	14	2	2	1	3	11	10	4	10	11	8	15	15	14	15	

1 means direct relations; 1* means transitive relations

De Dependence power, *Dr* Driving power

Table 4 Iteration 1 for level partitioning

Code	Reachability set	Antecedent set	Intersection set	Level
BR1	1,6,7,9,10,11,12,13,14,15	1,2,3,4,5,6,7,8,9,11,12,13,14,15	1,6,7,9,11,12,13,14,15	
BR2	1,2,6,7,9,10,11,12,13,14,15	2,4	2	
BR3	1,3,5,6,7,8,9,10,11,12,13,14,15	3,4	3	
BR4	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	4	4	
BR5	1,5,6,7,8,9,10,11,12,13,14,15	3,4,5	5	
BR6	1,6,7,9,10,12,13,14,15	1,2,3,4,5,6,7,8,9,10,15	1,6,7,9,10,15	
BR7	1,6,7,9,10,12,13,14,15	1,2,3,4,5,6,7,8,9,10	1,6,7,9,10	
BR8	1,6,7,8,9,10,11,12,13,14,15	3,4,5,8	8	
BR9	1,6,7,9,10,12,13,14,15	1,2,3,4,5,6,7,8,9,10	1,6,7,9,10	
BR10	6,7,9,10,12,13,14,15	1,2,3,4,5,6,7,8,9,10,15	6,7,9,10,15	
BR11	1,11,12,13,14,15	1,2,3,4,5,8,11,15	1,11,15	
BR12	1,12,13,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1,12,13,15	1
BR13	1,12,13,14,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1,12,13,14,15	1
BR14	1,12,13,14,15	1,2,3,4,5,6,7,8,9,10,11,13,14,15	1,13,14,15	
BR15	1,6,10,11,12,13,14,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1,6,10,11,12,13,14,15	1

Autonomous challenges: The first quadrant is used to group challenges, including weak drive and dependence power. This study has no autonomous challenges from the recognized list of potential challenges (see Fig. 3).

Dependent challenges: The second quadrant is where challenges that have poor driving but significant dependence power are grouped. From the attained list, the challenges, such as *'Lack of multi-channel purchasing*

Table 5 Iterations 1 to 8 for level partitioning

Code	Reachability set	Antecedent set	Intersection set	Level
BR1	1	1,2,3,4,5,8	1	4
BR2	2	2,4	2	5
BR3	3	3,4	3	7
BR4	4	4	4	8
BR5	5	3,4,5	5	6
BR6	1,6,7,9,10	1,2,3,4,5,6,7,8,9,10	1,6,7,9,10	3
BR7	1,6,7,9,10	1,2,3,4,5,6,7,8,9,10	1,6,7,9,10	3
BR8	8	3,4,5,8	8	5
BR9	1,6,7,9,10	1,2,3,4,5,6,7,8,9,10	1,6,7,9,10	3
BR10	6,7,9,10	1,2,3,4,5,6,7,8,9,10	6,7,9,10	3
BR11	1,11	1,2,3,4,5,8,11	1,11	3
BR12	1,12,13,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1,12,13,15	1
BR13	1,12,13,14,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1,12,13,14,15	1
BR14	1,14	1,2,3,4,5,6,7,8,9,10,11,14	1,14	2
BR15	1,6,10,11,12,13,14,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	1,6,10,11,12,13,14,15	1

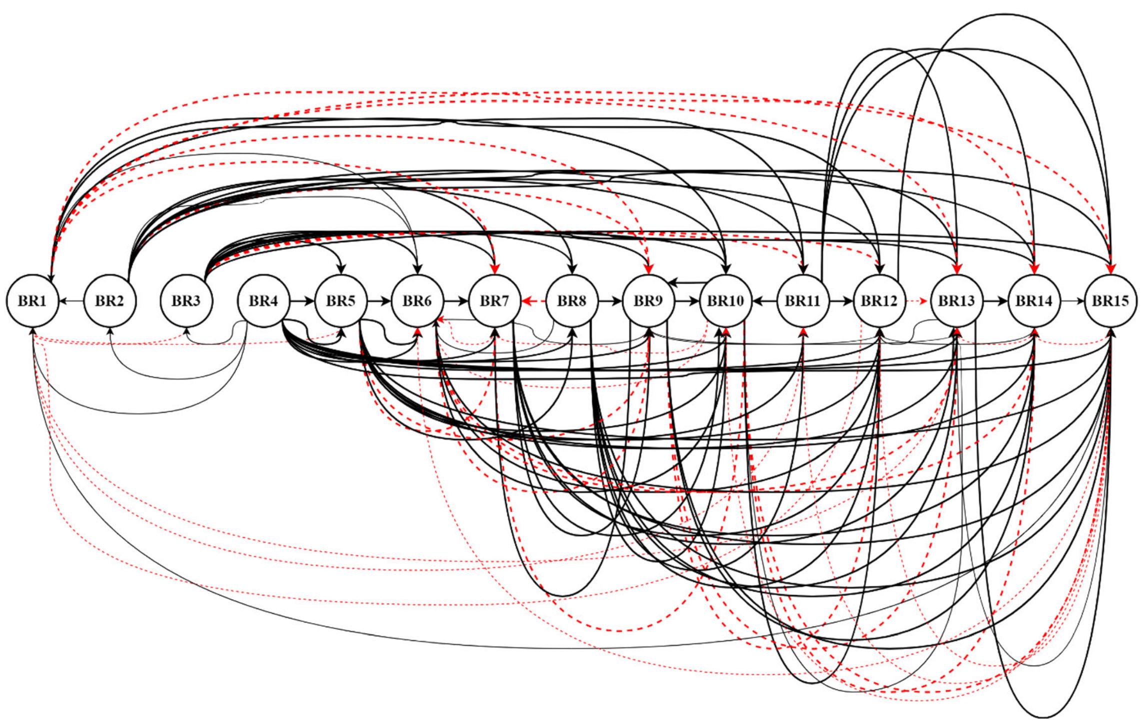

Fig. 1 Diagraph reflecting inter-relationships among business recovery challenges

strategies (BR10), 'Lack of ease of supplier geo-relocation (BR11),' ' Lack of reconfiguring production lines (BR12),' 'Lack of product competencies to meet disturbances (BR13),' 'Disconnected workflows and processes (BR14),' 'Less adoption of robust technologies (BR15) are placed as dependent challenges.

Linkage challenges: The third quadrant is where challenges with high dependence and driving power are grouped. In this study, challenges such as *'Poor*

Fig. 2 Inter-relationships among business recovery challenges

communication among supply chain stakeholders (BR1),' ' Unauthorized subcontracting and raw material sourcing (BR6),' ' Lack of real-time data on supply chain operations (BR7),' and 'Lack of transparency in supply chains (BR9),' are identified as linkage challenges from the identified list of potential challenges (see Fig. 3).

Independent challenges: The fourth quadrant is used to group challenges that have strong driving forces but weak dependencies. The challenges such as *'Lack of collaboration between stakeholders (BR2),' 'Lack of management support toward building resilience (BR3),' ' Lack of flexible policies for handling disruptions (BR4),' 'Lack of financial capabilities to handle the disruptions (BR5),' and 'Lack of flexibility in the supply chain design (BR8)'* are categorized as independent challenges. Figure 3 shows the setup for the dependence and driving power investigation.

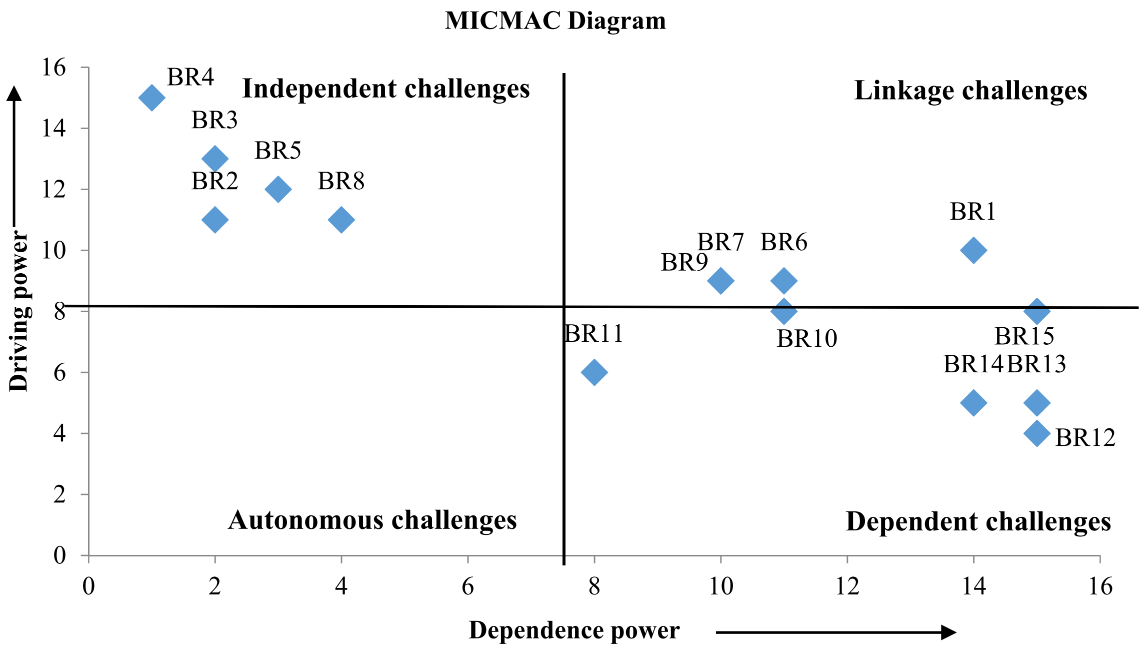

Fig. 3 Driving and dependence power of business recovery challenges

Discussions on Findings

The study performed an evaluation of prevailing literature to identify ways in which the manufacturing industry can mitigate the business recovery challenges for improving SCR in the post-pandemic world. The researchers consulted with experts in both industry and academia to determine how the various potential challenges interrelate, using the m-TISM methodology (as illustrated in Fig. 2). The resulting diagram of driving and dependent factors was analyzed to identify the specific connections between the possible challenges that were identified. The m-TISM model obtained can be examined in eight separate levels.

The challenges *Lack of product competencies to meet disturbances (BR13), Lack of reconfiguring production lines (BR12), and Less adoption of robust technologies (BR15)* occupy the first level. A lot of manufacturing has moved into low-cost regions, for example, India, Malaysia, Thailand and Vietnam, and many organizations do not have the expertise or knowledge to adapt their products to changing market conditions or address supply chain disruptions effectively. For example, thousands of laptop orders remain unfulfilled due to slowdowns in the manufacture of microchips; even basic consumer products like bicycle had their parts in short supply worldwide (KPMG, 2022). As a result, they may struggle to continue a consistent movement of goods and services, which could lead to increased costs and lost revenue. Developing product design and adaptation competencies is crucial for companies seeking to build a more RSC in the face of future disruptions (Wang et al., 2018; Ghadge et al., 2022). Another challenge in designing a RSC in the post-pandemic world is the '*lack of flexibility in production lines.*' Organizations that rely on fixed production lines may struggle to revise rapidly due to variations in demand or supply chain disruptions (Chowdhury et al., 2021). For example, suppose a particular product suddenly becomes more popular. In that case, a company with inflexible production lines may be unable to upgrade production quickly enough to satisfy the increased demand. Similarly, if a key supplier experiences disruptions, a company with fixed production lines may not be able to easily switch to alternative suppliers. Developing the ability to reconfigure production lines quickly and efficiently will be critical for an organization seeking to build a RSC in the future (Tukamuhabwa et al., 2017).

'*Less adoption of robust technologies'* is another challenge in designing a RSC in the post-pandemic world. Manufacturing organizations that rely heavily on complex and interdependent technologies may face difficulties in the event of disruptions to their supply chains or production processes (Chopra et al., 2021). Developing a more diverse and resilient technology infrastructure will be crucial for companies seeking to build a RSC in the aspect of future disruptions. Thus, ranking these three challenges at the highest level reflects the need to mitigate them to design a

RSC in the post-pandemic world. The challenge, *Disconnected workflows and processes (BR14)*, comes at the second level. Manufacturing organizations that have disconnected or siloed workflows may struggle to respond quickly and effectively to disruptions like COVID-19. To mitigate this challenge, there is a need for effective coordination with various departments to adjust production plans, manage inventory levels, and communicate with customers. If these workflows are not well-coordinated, the response may be slow and inefficient, leading to increased costs and lost revenue (Monostori & Váncza, 2020). Developing more integrated and collaborative workflows will be crucial for organizations in building a RSC in the face of future disruptions.

'Lack of ease of supplier geo-relocation (BR11),' 'Lack of multi-channel purchasing strategies (BR10),' 'Lack of transparency in supply chains (BR19),' 'Unauthorized subcontracting and raw material sourcing (BR6),' 'Lack of real-time data on supply chain operations (BR7)' are positioned at third level in the m-TISM diagram. Organizations may need to quickly shift their supply chain to alternative raw materials or finished product sources when a disruption occurs. However, the process of finding new suppliers and relocating production facilities can be complex, time-consuming, and costly. However, looking at regional development, one witnesses an important shift in global manufacturing in the relocation, diversification, and reshoring arrangement. In 2020, the trade ministers of Australia, Japan, and India entered into an Australia–Japan–India trilateral treaty to construct a program related to SCR for the Indo-Pacific region. It has been recognized that the region is critical for global supply chain supplies and hence requires better resilience (Asiasociety, 2023). In some cases, suppliers may be located in countries or regions with strict regulations or unstable political situations, which can make it problematic for organizations to quickly relocate their supply chain. Organizations can design a RSC by investing in robust and advanced technologies, expanding their supplier base, and employing policies for managing risk efficiently (Okorie et al., 2020). In addition, a lack of multi-channel purchasing strategies can limit the ability of organizations to counter rapidly to changing market conditions. Organizations can reduce their reliance on a single supplier and ensure continuity of operations by implementing a multi-channel purchasing strategy and leveraging technology to advance SCR (Büchi et al. 2020).

A *'lack of transparency in supply chains'* can make it difficult for organizations to identify potential risks and disruptions in the supply chain. To overcome these challenges, organizations can take steps to improve transparency in their supply chains and leverage technology to enhance supply chain agility. This can include implementing supply chain management systems that can track and monitor suppliers and raw materials and investing in real-time data analytics to recognize potential risks and opportunities in the supply chain. Additionally, unauthorized subcontracting and raw material sourcing can create additional supply chain risks, as organizations may not be able to verify the quality of the products or services provided by these subcontractors or raw material suppliers. Without real-time data, organizations may be unable to quickly identify supply chain disruptions or respond to market conditions changes. This can lead to delays in production, excess inventory, and lost revenue. Another challenge that organizations may face in designing a RSC is *'poor communication among supply chain stakeholders (BR1),'* which is positioned at the fourth level. Effective communication among supply chain stakeholders is critical to ensure that all parties are aligned on key objectives and able to coordinate their activities effectively. Poor communication can lead to misunderstandings, delays, and other issues that can disrupt supply chain (Wang et al., 2018).

'Lack of flexibility in the supply chain design (BR8)' and 'the lack of collaboration between stakeholders (BR2)' can act as significant challenges in designing a RSC for manufacturing organizations in the post-pandemic world and is positioned at the fifth level. To overcome these challenges, organizations can design their supply chains considering flexibility in the picture. This can include identifying alternative sources of supply, developing contingency plans for disruptions, and implementing supply chain management systems that enable real-time monitoring and visibility (Remko, 2020). *'Lack of financial capabilities to handle the disruptions (BR5),' 'lack of management support toward building resilience (BR3),' and 'lack of flexible policies for handling disruptions (BR4)'* are the challenges that are positioned at the sixth, seventh, and eighth levels, respectively.

'Lack of financial capabilities to handle disruptions' can make it difficult for organizations to invest in the resources and infrastructure required to build a RSC. Organizations must explore alternative financing options, such as partnerships with suppliers and other stakeholders or leveraging government support programs. Additionally, organizations can prioritize investments in the most critical areas for building resilience. Also, without '*the commitment and leadership of senior management,'* efforts to build a RSC may be deprioritized or lack sufficient resources. Thus, by exploring alternative financing options, prioritizing investments in resilience, communicating the importance of these efforts to senior management, appointing a dedicated SCR team, and developing flexible policies and procedures, organizations can reduce the risks

of disruptions and safeguard the stability of processes (Ramezankhani et al., 2018).

In the m-TISM framework, the relationship among the challenges is depicted by an arrowhead. Afterward, the driving power and dependence power of the recognized potential challenges are determined by exercising the MICMAC analysis. The MICMAC methodology categorizes the identified challenges as shown in Fig. 3. The findings from the current study reveal that challenges such as '*lack of flexible policies for handling disruptions (BR4),' 'lack of management support toward building resilience (BR3),' and 'lack of financial capabilities to handle the disruptions (BR5)'* have the highest driving power. The highest driving power of these business recovery challenges specifies their urgency to be mitigated immediately for designing a RSC in the manufacturing industry in the post-pandemic world. Further, '*lack of reconfiguring production lines (BR12),' 'lack of product competencies to meet disturbances (BR13),' and 'disconnected workflows and processes (BR14)'* emerge to be the challenges with minimal driving power. Hence, MICMAC analysis facilitates the practitioners to evaluate the influence of each recognized business recovery challenge on the remaining challenges. Further, the m-TISM approach can be complemented by using a system thinking approach. Focusing on the whole picture, thinking long term rather than short term, cause and effect thinking are some of the fundamental tenets of systems thinking (Elias, 2021).

Implications of the Study

Based on the findings of the study and literature support, this section discusses implications for managers, businesses, government and policymakers.

Managerial Implications

The COVID-19 pandemic has significantly impacted the manufacturing industry, causing unprecedented challenges and global supply chain disruptions. Therefore, this study analyzed the manufacturing industry's business recovery challenges and discussed suggestions to address them. The study identified 15 business recovery challenges and established a framework that can assist managers in designing a RSC in manufacturing organizations. It highlights the importance of investing in developing a flexible and adaptable product portfolio, prioritizing workforce training and development, collaborating with supply chain partners, diversifying sourcing options, establishing multilateral regional trade alliances, and adopting new technologies and tools to improve production competencies. Such findings have also been relevant in developing business resiliency in the Indo-Pacific region (Lund et al., 2020).

Manufacturing practitioners should consider adopting new technologies and tools to help them respond quickly to changing market demands. This could include investing in manufacturing technologies for collaboration and innovation to improve product quality and reduce production times. Such findings are also endorsed by Bhaskar (2021), which emphasizes the Indian Government's partnership and involvement in developing the marine commerce potential of the Pacific region.

In addition to managing product design capabilities, managers should prioritize developing a flexible and adaptable product portfolio that can quickly respond to changes in the market. They can achieve this by capitalizing on research and development to recognize new products or adapting existing products to meet changing customer demands. Such findings have also been endorsed by Fountain et al. (2021) study on New Zealand and adjoining Pacific islands, where they called for diversifying from beach and sightseeing tourism and processing recovery in marine resources.

The COVID-19 pandemic has recognized the prominence of Information and Communication technologies in addressing the information and social distancing adept supply needs. Although it accelerated digital adoption, the Indo-Pacific region is witnessing a deeper digital divide between and within countries, reinforcing a vicious cycle of economic inequalities. Digitization is a great enabling tool for achieving supply chain resiliency. An initiative under the name Quad Technology Network was suggested to promote public debate on critical cyber and technology issues (Ray et al., 2021). By leveraging digital technologies, manufacturing organizations can quickly adapt their operations to meet changing customer demands, thereby improving SCR. Practitioners can focus on building a strong and robust technological infrastructure, which can help manufacturing organizations have greater mechanisms over their supply chain. Further, the study suggests that organizations invest in flexible and adaptable production systems that can quickly reconfigure to produce new products or accommodate changes in production demand. This could involve redesigning production lines and investing in new technology to enhance efficiency and responsiveness. Contingency plans that outline alternative sourcing options, manufacturing locations, and logistics strategies should also be implemented to minimize the impact of future disruptions and ensure sustained operations.

Implications for the Pacific

The implications, particularly in the context of the Pacific region, are crucial for enhancing SCR in the geographic and economic context. The region, with its remote islands and scattered nations, often faces challenges related to geographic isolation. The framework developed in this study can benefit regional businesses and policymakers in identifying and mitigating recovery challenges specific to their isolation, such as limited transportation options and higher vulnerability to supply chain disruptions. It comprises diverse economies, including developed countries, emerging markets, and least developed nations. The framework's analysis of 'lack of product competencies to meet disturbances' can help identify areas where different economies can collaborate to enhance product competencies. This collaboration can be facilitated through regional economic organizations and agreements. The framework can help businesses and Government navigate complex trade dynamics and develop strategies that enhance regional and international cooperation during recovery.

The region's unique cultural and social characteristics significantly contribute to business operations. The framework's insights can be used to address cultural and social factors affecting resilience. For instance, 'lack of management support toward building resilience' can be adapted to encourage more inclusive and community-driven approaches to recovery. The region is also susceptible to climate change-related disruptions. The framework can be used to develop strategies that consider the impact of climate-related challenges on business recovery. For example, it can guide manufacturing firms in creating climate-resilient supply chains and product lines. Due to limited local resources, many South Pacific nations rely on imported raw materials and goods. The framework's identification of challenges like 'lack of flexible policies for handling disruptions' and 'less adoption of robust technologies' can be tailored to address the resource dependency of the region. Policymakers can focus on developing resilient sourcing strategies and encouraging the adoption of advanced technologies to decrease this dependency. By tailoring strategies to the region's unique characteristics and vulnerabilities, businesses and policymakers can better position the manufacturing industry for sustainable growth and resilience in the aspect of future disruptions.

Conclusions, Limitations, and Scopes for Future Research

This study investigates the business recovery challenges faced by manufacturing organizations in building RSCs that can withstand catastrophic disruptions like the COVID-19 pandemic. To attain this, the study uses m-TISM methodology to analyze responses from Indian industry experts and establish a framework for determining inter-relationships among business recovery challenges that impede firms from building RSCs. Although the data for analysis were appropriated from the Indian manufacturing sector, its implications can be very established to the Pacific region given the cultural, geo-political and social similarities. The study's contributions include identifying and analyzing business recovery challenges, constructing a framework of interrelated challenges, and providing recommendations for addressing the identified challenges. The study highlights the need to mitigate the lack of reconfiguring production lines, product competencies, and adoption of robust technologies to build RSCs.

Among the limitations, one can object to the generalizability of the findings as experts' opinions were taken from one country and not expanded to other partners of the region. One can validate and enrich the study by exploring other countries of the region; however, the authors opine that there will be minor differences. Therefore, future research could consider a longitudinal study to monitor changes in recovery challenges, analyze recovery challenges for different supply chains and regions, and explore challenges facing other industries in the Pacific region.

In conclusion, this study offers a comprehensive set of business recovery challenges that can guide decision-makers in the manufacturing industry. The study's conclusions can support in the formulation of recovery strategies that can enhance SCR and optimize the business recovery process. Overall, this study adds to the literature on building RSCs and employs mixed methodologies to advance a framework that can aid the decision-makers of the manufacturing industry.

Appendix

See Tables 6 and 7

Table 6 Details of the experts

Experts	Domain	Experience (Years)
Expert 1,2	Supply chain manager	> 8
Expert 3,4,5	Operations manager	> 15
Expert 6,7,8	Procurement services, logistics	> 10
Expert 9	Supply chain resilience researcher	> 3

Table 7 Interpretive matrix for business recovery challenges

No.	1	2	3	4	5	6	7	8	9	10	11	12	13
1				Poor communication affects raw material sourcing	Poor communication affects real time data collection		Poor communication affects transparency	Poor communication affects purchasing strategies	Poor communication affects supplier geo-relocation				
2	Lack of collaboration affects communication												
3			Lack of management support affects financial capabilities										
4		Lack of flexible policies affects management											
5						Lack of financial capabilities affects flexibility							
6				Lack of real-time data affects raw material sourcing								Lack of real-time data affects workflow and processes	
7	Lack of flexibility affects communication												
8				Lack of transparency affects raw material sourcing				Lack of transparency affects purchasing strategies				Lack of transparency affects workflow and processes	
9											Production lines affect product competencies		
10										Disconnected workflows affect the reconfiguration of production lines	Disconnected Workflows affect product competencies		Disconnected workflows affect robust technologies
11											Robust technologies affect product competencies		

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Declarations

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

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Key Questions

1. What are the business recovery challenges in the manufacturing industry?
2. How can the inter-relationships among business recovery challenges be investigated?
3. In what way can the driving-dependence influence of each business recovery challenge be obtained?

Ashish Dwivedi works as a Professor in Operations Management and Decision Sciences at Jindal Global Business School, O.P. Jindal Global (Institution of Eminence Deemed to be University), Sonipat. He holds a doctorate (PhD) from the Department of Management Studies, Indian Institute of Technology Delhi, India. He holds an MTech degree in Mechanical Engineering with a specialization in Computer Aided Design and Manufacturing from Motilal Nehru National Institute of Technology Allahabad, Prayagraj, India. He is an Engineering graduate in Mechanical Engineering. He has received the second prize in the Basant Kumar Birla Distinguished Researcher Award 2022 based on the count of ABDC A / ABDC A* / ABS 4-level publications over five years. His research has been published in various journals of international repute, including Journal of Cleaner Production, Business Strategy and the Environment, Annals of Operations Research, International Journal of

Production Research, and Technological Forecasting and Social Change.

Shefali Srivastava is an Assistant Professor at CHRIST University, Bangalore. Her research interests mainly include sustainability, circularity, servitization, value co-creation, and quality management. She obtained her PhD in Service Operations Management from the Indian Institute of Information Technology and Management, Gwalior, in 2019. She completed her post-doc at the Indian Institute of Technology, New Delhi, in circular supply chains. She has published several research papers in eminent Scopus and ABDC, ABS-indexed journals. She has also received 'HIGHLY COMMENDABLE PAPER - LITERATI AWARDS-2020' by EMERALD Publishers in 2020. She is also included in the P-ranking list of the top 500 researchers in the South Asian Region in business and management.

Dindayal Agrawal works as an Assistant Professor in Operations Management at the Institute of Management Technology, Ghaziabad, Uttar Pradesh, India. He holds a PhD from the Department Of Management Studies, Indian Institute of Technology, Delhi, India. He also holds an MTech degree in Industrial Engineering from the Indian Institute of Technology, Delhi, India. He has completed his BTech in Mechanical Engineering. His research has been published in various journals of international repute, including Annals of Operations Research, Business Strategy and Environment, Computers and Industrial Engineering, Global Journal of Flexible Systems Management, International Journal of Logistics Management, and Industrial Management & Data Systems. He has also presented his research works at various international conferences in the USA and India. His teaching interests include operations management, optimization, supply chain management, multi-criteria decision-making, data analytics, and visualization.

Ajay Jha is working as an Associate Professor at Jaipuria Institute of Management, Lucknow. He has a PhD in Strategy Implementation (specifically technological innovation management and supply chain management) from the Indian Institute of Technology, Kanpur (IIT Kanpur), India. His other educational qualifications include a BTech (Mechanical Engineering) from HBTI, Kanpur, and MTech (Industrial and Management Engineering) from IIT Kanpur . He has more than ten years of teaching experience. His area of interest includes production planning and control, operations and supply chain management, and project management. He also has extensive industrial experience of ten years in different domains, such as sales and marketing, project management, and safety audit and control. He has published in top-ranked International journals and conferences, including Supply Chain Management: an International Journal, International Journal of Productivity and Performance Management, Management of Environmental Quality: An International Journal, The TQM Journal, and IEOM Conferences.

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