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INVITED PAPER

Supply Chain Flexibility and Post-pandemic Resilience

Nishant Agrawal[1] · Mahak Sharma[2] · Rakesh D. Raut[3] · Sachin Kumar Mangla[4] · Sobhan Arisian[5]

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Abstract *The COVID-19 outbreak in 2020–2021 caused unprecedented disruptions to global supply networks. Companies worldwide faced significant challenges as they dealt with the unexpected surge in demand for specific goods and services. This study delves into the importance of supply chain coordination (SCCO), supply chain resilience (SCRE), and supply chain robustness (SCRB), considering supply chain flexibility (SCFL) and Internet of Things and Big Data Analytics (IoT-BDA) integration. We explore how SCFL influences SCCO, SCRE, and SCRB, enhancing supply chain performance (SCFP). Using a cross sectional approach, we collected survey-based responses to ensure comprehensive representation from the supply chain domain. A total of 217 complete responses were collected and analyzed using AMOS 20. The findings suggest that SCCO, SCRE, and SCRB act as mediators between SCFL and IoT-BDA. However, statistical significance between SCCO and SCRB with SCRE was not established. The study emphasizes the robust predictive nature of SCFL, highlighting its pivotal role in fostering SCCO, SCRE, and SCBR through empirical evidence. Furthermore, it emphasizes the influence of SCFL on enhancing SCFP, particularly in the post-pandemic era.*

Keywords Flexibility · IoT-BDA · Performance · Resilience · Robustness · Supply chain management (SCM)

JEL Classification C61 · C67

✉ Sobhan Arisian
S.Asian@latrobe.edu.au

Nishant Agrawal
nishant4uagr@gmail.com

Mahak Sharma
m.sharma@utwente.nl

Rakesh D. Raut
rraut@nitie.ac.in

Sachin Kumar Mangla
sachinmangl@gmail.com

1 ICFAI Business School (IBS) – Ahmedabad, Koba-Adalaj Rd, Opp. Annapurna Dham, Ahmedabad, Gujarat 382421, India

2 Faculty of Behavioural, Management and Social Sciences (BMS), Industrial Engineering and Business Information Systems (IEBIS), University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

3 Department of Operations and Supply Chain Management, Indian Institute of Management (IIM), Vihar Lake, Powai, Mumbai, Maharashtra 400087, India

4 Research Centre 'Digital Circular Economy for Sustainable Development Goals (DCE-SDG)', Jindal Global Business School, O P Jindal Global University, Sonipat, Haryana, India

5 La Trobe Business School, La Trobe University, Level 4, Martin Building, Bundoora, Melbourne, VIC 3086, Australia

Introduction

Over the last three decades, supply chains (SCs) have undergone a significant evolution, leading to a notable increase in the outsourcing of supply chain management (SCM). Simultaneously, the management of material, information, and financial flows within manufacturing SCs encounters substantial challenges due to the involvement of multiple entities in the broader value transformation processes (Lu et al., 2018a; Power, 2005; Sharma et al., 2023a). The primary sources of disruption arise from the dynamic nature of customer needs and the continuous advancements in technology, leading SCs to outsource a variety of value transformation processes (Naeem & Garengo, 2022; Sharma et al., 2021).

The COVID-19 pandemic triggered one of the largest economic crises in our rapidly evolving modern world, causing significant disruptions and challenges for both service and manufacturing firms (Butt, 2021; El Korchi, 2022; Fortune, 2020; Queiroz et al., 2021). For example, the Pacific region faced distinct challenges and opportunities across economic, social, environmental, and political domains. In Fiji, the tourism sector experienced a severe downturn during the pandemic, with revenues plummeting by 84.4% in 2020 compared to 2019, underscoring the magnitude of the impact (Asian Development Bank, 2022). Nevertheless, the tourism sector demonstrated resilience in 2022, experiencing a significant recovery as 59.8% of visitors arrived in the first seven months of the year, mirroring the figures from 2019 and indicating a positive trajectory in the sector's recovery (Fiji Reserve Bank, 2022).

Supply chain resilience (SCRE) is commonly assessed at the firm or SC level. However, given the global impact of the COVID-19 crisis, which not only devastated businesses and SCs worldwide but also ruthlessly affected global public health, the traditional units of analysis for resilience have proven insufficient in addressing the endurance and survival of firms within this context (Golan et al., 2020). A crucial aspect in addressing crises lies in adopting a systems thinking approach, a fundamental requirement for both researchers and practitioners in the context of SCM (Nilsson & Gammelgaard, 2012; Stock et al., 1999).

Prior studies suggest that comprehending SCM requires an understanding of systems, enabling a holistic viewpoint, an appreciation for total cost, and the mitigation of suboptimal outcomes (Grant et al., 2005). However, it is notable that positivism prevails when applying a systems thinking approach to SCM research (Elias et al., 2021). Applying systems thinking in SC management involves viewing the SC as an interconnected and interdependent system rather than focusing on individual components in isolation (Nilsson & Gammelgaard, 2012). This holistic approach aims to understand the relationships and dynamics within the entire SC network, thereby facilitating better decision-making, improved efficiency, and increased resilience.

Agile organizations constantly revisit their strategies to establish a robust framework that mitigates the adverse effects of disruptions and readily adopts proactive measures (Frederico, 2021; Paul et al., 2019; Tukamuhabwa et al., 2017). Enterprises that exhibit receptivity to exploration, experimentation, and the adoption of emerging technologies have demonstrated superior performance compared to their competitors (Giraldi et al., 2023; Gunasekaran et al., 2017). Furthermore, firms actively seek access to comprehensive information concerning the perpetually evolving market, enabling them to acquire knowledge and amplify their capacity to flourish within this dynamic environment.

The recent surge in "*big data*" plays a significant role in informing decisions across various industries (Gu et al., 2021; Kafetzopoulos et al., 2023; Qu et al., 2022). In manufacturing, real-time data are particularly essential for ensuring smooth operations and providing accurate input to intelligent machines. A growing trend toward an "*economy of things*," an advanced version of the "*Internet of Things (IoT)*," is gaining traction, offering precise real-time data. Big data analytics (BDA) and IoT technology are receiving significant attention in this context (Arunmozhi et al., 2022; Kumar et al., 2022a, 2022b; Wang et al., 2020). These technologies contribute to establishing transparent processes in the value chain, thereby fostering consumer trust. The synergy of IoT and BDA, known as IoT-BDA, has the potential to expedite product delivery, enhance traceability, and synchronize partners (Sarkis et al., 2020). Such integration can unlock the full potential of data generated across SCs, fostering innovation and efficiency in industries such as manufacturing, healthcare, agriculture, transportation, and smart cities, among others (Liu et al., 2023).

The BDA market in SCM, valued at USD 3.55 billion in 2020, is projected to reach USD 9.28 billion by 2026, demonstrating a Compound Annual Growth Rate of 17.31% over the forecast period (from 2021 to 2026).[1] However, the efficacy of investing in technology, developing new capabilities, and intelligently applying IoT-BDA to augment business performance has yielded mixed results, as reported in recent studies by Gu et al. (2021) and AL-Khatib et al. (2022, 2023).

The Covid-19 crisis has spurred rapid research efforts aimed at developing more resilient SCs and innovative

[1] https://www.mordorintelligence.com/industry-reports/global-supply-chain-big-data-analytics-market-industry.

recovery strategies. Various dimensions of resilience across different regions and sectors have been explored and documented in scholarly literature, as highlighted by Elias (2021). Existing literature on SCM emphasizes the potential for enhancing SC capabilities through the integration of information and communication technology within SC processes. However, prior research has not empirically explored whether technological advancements and the adoption of flexible, resilient, and robust SC strategies contribute to enhanced SC performance. To address these research gaps, this study examines the relationships between SC coordination, resilience, robustness, IoT-BDA, and their impact on SC performance. The paper empirically tests whether a flexible SC can enhance both resilience and robustness, ultimately leading to improved overall SC performance. In particular, this work seeks to address three specific research questions:

RQ 1 How do SCBR, SCRE, and SCCO influence IoT-BDA?

RQ 2 How does IoT-BDA influence SCFP?

RQ 3 Do mediating variables such as SCBR, SCRE, and SCCO strengthen the relationship between SCFL and IoT-BDA?

Competitive dynamics and advancements drive firms to pursue innovative and distinctive strategies (Kani et al., 2022; Sharma and Sehrawat, 2021; Wójcik, 2015). The formulation and execution of these strategies lead to the creation of novel approaches for judiciously utilizing resources to achieve enhanced performance and gain a competitive edge (Sharma et al., 2023b). The current study employs a mixed methods approach (Sharma et al., 2022a) to assess specific SC values, such as coordination, flexibility, resilience, and robustness, while investigating the impact of IoT-BDA on improving SCFP. This study follows the framework developed by Sharma et al. (2022a) to gauge SC-specific values. The research probes the influence of IoT-BDA in elevating SCFP, guided by an extensive review of pertinent literature. While some research addresses the adverse effects of disruptions on SC performance (Parast & Subramanian, 2021; Zhang et al., 2021), limited investigation exists into how performance can be achieved through the interplay of IoT-BDA, resilience, and flexibility, particularly in the context of the Covid-19 pandemic. To investigate these dimensions, a cross sectional survey involving 217 participants, including SC managers, HR managers, procurement managers, warehouse personnel, and inventory managers, was conducted. The resultant model has been examined through this survey-based approach.

This study makes the following contributions: Firstly, it explores the potential linkage between dynamic capability theory (DCT) and the resource-based view (RBV). Secondly, it employs a technology-oriented approach to comprehensively examine critical dimensions of the SC for overall performance, emphasizing the pivotal role of understanding risk exposure in determining the necessary resilience level for SC endurance under extreme circumstances. This insight is crucial for policymakers and SC professionals, enabling them to craft effective strategies and plans to mitigate the adverse consequences of risks. Thirdly, the study highlights the impact of IoT-BDA on SCFP, emphasizing the imperative for SC practitioners to persuade senior management of the value in adopting appropriate strategies to enhance IoT-BDA implementation. The findings are expected to offer valuable insights for SC managers and operators, showcasing the pivotal role of strategic planning in enabling SCs to recover, adapt, and respond effectively to disruptions of varying durations, intensities, and probabilities.

The remainder of this paper is structured as follows: Section "Theoretical Background" presents the theoretical background. Section "Hypothesis Development" provides a detailed explanation of the Hypothesis development and research framework. The measurement model and hypothesis testing are presented in Sect. "Measurement Model". Finally, Sect. "Conclusion" discusses the study's conclusion, implications, and future works.

Theoretical Background

RBV and DCT are two critical theoretical perspectives that are often used to explain how firms can achieve competitive advantage in their respective industries (Salgado et al., 2022). In SCM, RBV and DCT can be applied to help firms develop and sustain their competitive advantage over time (Sharma et al., 2023c; Sahu et al., 2024). The RBV suggests that a firm's resources and capabilities are the key determinants of its ability to achieve sustainable competitive advantage (Yoshikuni et al., 2023). From this standpoint, a firm's CA stems from its distinct combination of resources and capabilities, making it challenging for competitors to imitate or replicate (Sharma et al., 2022a; Wided, 2023). For example, a firm may have unique relationships with suppliers, access to specialized technology, or a highly skilled workforce that allows it to optimize its SC operations and achieve cost savings or higher quality products (Agrawal, 2022; Agrawal et al., 2023; Sharma et al., 2022b)

DCT suggests that a firm's ability to adapt to change is the key to its long-term success (Gupta & Gupta, 2019). From this viewpoint, CA is resulting from firm's ability to sense, seize, and transform opportunities in its environment (Siva Kumar & Anbanandam, 2020). DCT firms can leverage their resources and capabilities to improve their SC operations and achieve superior performance (Awwad et al., 2022). In SCM, firms can use dynamic capabilities to respond to changes in customer demands, new technologies, or shifts in market conditions (Salgado et al., 2022). For example, a firm may be able to quickly reconfigure its SC network to respond to changes in customer preferences or adapt to disruptions in the SC caused by natural disasters or other unforeseen events. RBV and DCT can be applied in SCM to help firms develop and sustain their competitive advantage (Gupta & Gupta, 2021). Firms can use RBV to identify their unique resources and capabilities and leverage them to improve their SC operations (Gupta et al., 2022). Firms can also use DCT to develop their adaptive capacity and respond to environmental changes. RBV and DCT provide a robust framework for firms to develop and sustain their competitive advantage in the dynamic and rapidly changing world of SCM (Bhandari et al., 2004).

DCT is "the ability to integrate, build, and reconfigure internal and external competencies to adjust to rapidly changing environments" (Teece, 2018). Hence, a firm should have plans and well-structured strategies to combat adversities. It is also worth noting that SC flexibility is the backbone for an RBV (Rezaei Somarin et al., 2018), making a firm more efficient and performing better in this competitive world (Wided, 2023). Technology can be critical to rapidly retort to extreme situations for cost minimization, mass customization, or production of new goods (Correia et al., 2022; Sharma et al., 2022a). The capabilities perspective has evolved within the RBV (Wójcik, 2015).

The COVID-19 pandemic is a disruptive impediment, especially for the manufacturing sector, which has eroded the entire SC and overall sectorial growth (Siagian et al., 2021). The manufacturing sector has witnessed serious concern in fulfilling the user demand globally and locally (El-Baz & Ruel, 2021). The COVID-19 risk mitigation led to a sharp decline in production capacity due to lockdown restrictions leading to the non-availability of workforce and personnel. Manufacturing uncertainty due to unexpected events demands measures to help a firm maintain a stable production environment (Luiz & Beuren, 2023; Sreedevi & Saranga, 2017).

In recent scholarly works, it has been emphasized that SCs that are flexible, robust, and resilient can withstand extreme adversities such as the COVID-19 pandemic (El Baz & Ruel, 2021). In this uncertain environment, firms need to have a flexible SC that not only helps them to survive but also enables them to remain competitive in the market, even in adverse situations (Sreedevi & Saranga, 2017). Additionally, supply chain flexibility (SCFL) helps firms collaborate and ultimately perform better than their competitors (Bag & Rahman, 2023). SC robustness helps firms survive during a pandemic, while resilience assists in post-pandemic recovery (Aldhaheri & Ahmad, 2023; Ivanov & Dolgui, 2020). The COVID-19 pandemic tested the resilience and robustness of SCs across industries, sectors, and geographies, as it led to a lack of reactivity (Ivanov and Dolgui, 2020). Recent literature suggests that the IoT-BDA can significantly impact firm performance in several ways (Bahrami & Shokouhyar, 2022). However, this relationship has not been studied in the context of manufacturing firms during the COVID-19 pandemic (Khan et al., 2021; Mohapatra et al., 2021).

Despite the growing academic and practitioner interest in SCM and IoT-BDA, especially during the pandemic (Anton et al., 2021; Kumar et al., 2021; Nayal et al., 2021), few studies have examined the impact of SC flexibility, coordination, resilience, and robustness, as well as IoT-BDA on SC firm performance.

The next subsection discusses the definitions of the constructs explored in the present context.

Resource-Based View (RBV)

The resourced-based theory emphasizes that a firm's knowledge and assets, if exploited properly, can enhance firm's competitiveness if and only if they are valuable, rare, non-duplicable, and non-substitutable (Khanra et al., 2022). The RBV is a valuable tool for assessing SC flexibility (Sharma et al., 2022a). By analyzing the resources available to a company, firm can determine how well it is positioned to respond to changes in the market and adapt to new challenges (Kumar et al., 2022a, 2022b). This approach can help firms to identify areas where they need to invest in order to improve their flexibility, such as by developing new partnerships, expanding their production capabilities, or investing in new technologies (Ozdemir et al., 2022). Ultimately, the goal is to create a SC that is agile, responsive, and resilient, capable of meeting the demands of customers and adapting to changing market conditions (Sharma et al., 2022a). RBV for SC coordination is a framework that emphasizes harnessing the distinct resources and capabilities possessed by each member within a SC. By doing so, it aims to achieve efficient and effective coordination, leading to improved SCM outcomes. By leveraging the unique resources and capabilities of each member of the SC, organizations can achieve greater coordination, cost savings, and improved customer service (Sahu et al., 2023). This approach recognizes that each member of a SC brings its own set of resources and competencies, and that by coordinating these resources and competencies, the SC as a whole can achieve greater efficiency, higher quality, and better customer service. The key to implementing RBV for SC coordination is to identify the unique resources and capabilities of each member of the SC, and then to develop strategies that leverage these resources and capabilities in a coordinated way. For example, a manufacturer might have expertise in production processes, while a distributor might have expertise in logistics and transportation. By coordinating these two sets of resources, the SC as a whole can achieve greater efficiency and cost savings (Sharma et al., 2022a).

Dynamic Capabilities Theory (DCT)

Dynamic Capability is "the ability to integrate, build, and reconfigure internal and external competencies to adjust in accordance with the rapidly changing environments" (Teece, 2018). Hence, a firm should have plans and well-structured strategies to combat adversities. It is also worth noting that SC flexibility is the backbone for resource-based view which makes a firm more efficient and perform better in this competitive world. Technology can serve as critical capabilities to rapidly retort to extreme situations for cost minimization mass customization or production of new goods (Kumar et al., 2022b; Sharma et al., 2022a). The capabilities perspective has evolved within the RBV (Wójcik, 2015). To remain competitive in business, companies must maintain SC resilience (Ozdemir et al., 2022). This means developing flexible networks, agile decision-making, real-time visibility, and proactive risk management (Sharma et al., 2022a). Building these capabilities is essential for responding to challenges and staying ahead of the competition. Studies indicate that incorporating novel technology such as internet of things (IoT) can significantly enhance SC transparency and competitiveness (Quayson et al., 2023). Through the use of innovative features such as sharing information and tracking, companies can establish a circular SC. The dynamic capabilities of IoT allow companies to recognize customer demands and team up with suppliers to acquire recyclable materials, thus reinforcing their management of a circular SC (Quayson et al., 2023).

Research Gap

The COVID-19 outbreak has caused an economic downturn, emphasizing the need to create more robust SCs. This research seeks to investigate whether adaptable SCs can enhance efficiency and durability. The proper integration of technology has grown in significance for optimizing SCM. Employing cutting-edge technologies like artificial intelligence, the IoT, and BDA enables companies to monitor and analyze their SC operations in real-time. Consequently, this empowers them to make well-informed and timely decisions, ultimately enhancing the overall performance of their SCs. Utilizing technology in SCM offers several key advantages, with one of the main benefits being the capacity to automate diverse processes. For example, automating inventory management systems empowers businesses to streamline stock tracking, observe demand trends, and forecast future needs efficiently. This time-saving measure not only minimizes the likelihood of errors but also enhances decision-making concerning inventory management, ultimately leading to improved SC performance. Moreover, technology plays a critical role in creating a more resilient and robust SC by identifying and addressing potential risks and vulnerabilities. Through the examination of data derived from suppliers, customers, and various sources, businesses can effectively pinpoint potential disruptions within their SC and proactively adopt measures to alleviate them. Such actions may encompass incorporating redundancies into the SC, diversifying suppliers, or establishing contingency plans to effectively address unforeseen events. To sum up, technology is anticipated to improve SC flexibility, resilience, and performance. However, its practicality in the Indian context requires empirical investigation. By harnessing advanced technologies, businesses can achieve real-time visibility into their SC operations, automate tasks, and create a more resilient SC capable of handling unforeseen disruptions. This, in turn, enhances overall SC performance, leading to heightened efficiency and profitability. The findings from this research will aid SC managers in devising recovery strategies. Importantly, this study is the first of its kind to examine the influence of technology advancements on SC performance.

Hypothesis Development

Supply Chain Flexibility (SCFL)

It helps to effectively manage SC risks in the context of supply and demand uncertainty, i.e., better coordination of risk mitigation strategies (Simchi-Levi et al., 2018). SCFL is the competitive response to environmental uncertainty (Bag & Rahman, 2023). Different types of flexibility (operational, tactical, strategic, and SCFL) help a firm/ manufacturing unit survive and excel even in unfavorable conditions. SCFL is crucial, encompassing elements such as robustness, re-configuration, relationship management, logistics and inter-organizational information systems (Stevenson & Spring, 2007), which are of utmost importance. SCFL can be ameliorated by using reactive as well as proactive component approaches (Angkiriwang et al., 2014). SCFL helps a firm or a production unit to have better survival when encountering "softer" impediments (supplier relationships) as well as "hard" impediments (Gunasekaran et al., 2001). SCFL comprises practices that help build long-term relationships with consumers, manage consumers' grievances, and enhance customer relationships, consumer satisfaction, strategic supplier partnership, and information sharing. It is essential to remain competitive in the market, which can be achieved by having flexible SC. SCFL helps an organization reduce SC costs by keeping undifferentiated inventories. However, it is also essential to understand that sometimes following this entire process can be costly, and firms may have different importance of various flexibility dimensions (Angkiriwang et al., 2014; Wadhwa & Rao, 2004). Performance is "how well a firm can achieve its financial and market-oriented objectives." The previous literature has shown that SCFL positively influences firm performance (Li et al., 2006). Hence, it is necessary to explore if SCFL directly or indirectly impacts SC performance in the Indian context.

Supply Chain Coordination (SCCO)

Coordination is the responsibility shared by two or more organizations. It is also a practice where firms exchange joint planning, managing principles, implementation, and performance measurement information (Min et al., 2005). Coordination provides access to complementary resources and collaborative processes among SC partners that expand the gain pie due to timely and effective interaction (Soosay et al., 2008). Successful coordination transforms drastically from standard business practice, primarily exchanging free data, financial information, and operating plans (Min et al., 2005). Supply chain coordination (SCCO) refers to managing interdependent activities and processes across different organizations producing and distributing goods and services (Asian & Nie, 2014). Effective coordination among the various players in a SC is crucial to ensure the accurate delivery of the appropriate product to the designated location precisely when needed, and to achieve this with the minimal associated costs (Li et al., 2006).

It is evident from previous findings that flexible firms or SC have chances of better coordination which will improve the overall firm performance (Asian et al., 2020). In that line, the present authors emphasize the dire need to understand if SCFL impacts SCCO in Indian manufacturing. SCFL can enhance absorptive capacity via knowledge reach and richness, facilitating connectivity with partners and stakeholders (Liu et al., 2013).

Hypothesis H1: Supply Chain Flexibility is positively related to Supply Chain Coordination.

Supply Chain Resilience (SCRE)

SCRE refers to a SC's capacity to endure and rebound from unexpected disruptions, challenges, or adverse events effectively. SCRE prepares the system for unexpected events during disruptions and timely recovery by maintaining desired continuity of operations (Brandon-Jones et al., 2014). SCRE focuses on balancing both reactive (adjustments ex-post to changes) and proactive strategies (ex-ante measures to cope with turbulence) (Agrawal & Jain, 2021; Durach et al., 2015). The existing literature has widely tested the impact of SCRE on a firm's operational performance; however, the research on its impact on its financial or SC performance is still nascent (Agrawal & Jain, 2022; Chunsheng et al., 2020). A handful of studies have shown that SCFL is an antecedent SCR (Tukamuhabwa et al., 2015), and SCRE positively impacts SCFP (Altay et al., 2018). Few recent researchers have proposed that adopting BDA technology positively impacts sustainable SCFP (Edwin Cheng et al., 2021). Further, few recent works hypothesized that with technological advancements, the SCRE allowed a buffer for capacity maintenance and enhanced back-ups which can enhance SCFP or overall SC capabilities; however, these works still need empirical evidence, especially in terms of emerging economies (Mandal et al., 2016).

The design of the SC plays a central character while ascertaining the SCFL of the standing arrangement and the comfort with which the change can be implemented (Stevenson & Spring, 2007). SCFL has the ability of a SC to quickly and efficiently respond to changes in demand or supply without incurring high costs or disruptions. A flexible SC can quickly adapt to customer preferences, market trends, or unexpected events such as natural disasters or disruptions.

Hypothesis H2: Supply Chain Flexibility is positively related to Supply Chain Resilience.

Supply Chain Robustness (SCRB)

Supply chain robustness (SCRB) refers to the capacity of a SC to continue its functions even when facing disruptions that may be internal or external in nature (Brandon-Joneset al., 2014). Simchi-Levi et al. (2018) offered a mathematical model that proposes how SCFL can help increase SCRB; however, its applicability in the Indian context needs empirical investigation. The dearth of conceptual clarity cascades the need for conceptual formalization using unique theoretical bases and in-depth analysis using measurement models (Mackay et al., 2020). The capacity of a SC to endure and bounce back from disruptions or unforeseen occurrences is referred to as robustness. Robustness holds great significance in SCM due to the potential impact of disruptions like natural disasters, supplier bankruptcies, transportation delays, or geopolitical conflicts on the flow of goods, services, and information within the SC. By achieving SCFL, this helps establish a robust SC network.

Hypothesis H3: Supply Chain Flexibility is positively related to Supply Chain Robustness.

Relationship between Coordination, Resilience, and Robustness

SCCO is fundamental for efficiently managing enterprise risks related to supply related disruptions (Kotze et al., 2017; Wang et al., 2023). Across the globe, SCC, trust, and information sharing help companies increase their SCRE. SCRE informs SC members with the help of an early warning of disruptions and allows them to use a proactive strategy (Asgari et al., 2022).

In recent years, there has been a growing interest in the concept of SC resilience (Ozdemir et al., 2022). The capacity of certain SCs to rebound from disturbances more efficiently than others has ignited a discussion about resilience. The concept of resilience emphasizes that it is impossible to prevent all risks, thus necessitating a proactive and comprehensive approach to handling SC risks. This involves augmenting conventional risk management tactics with methods that can address unexpected disruptions and occurrences. SC resilience pertains to an organization's ability to endure, adjust, and thrive when faced with changes and uncertainties. It is defined as "the adaptive capability of the SC to prepare for unexpected events, respond to disruption and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structures and function." The notion can be likened to "shock absorption" occurring between various stages of the SC. Although there is little variation in how SCRE is defined in current literature, the specific components necessary to ensure the adaptability of resilience show substantial differences. In this paper, we adopt an existing resilient SC framework from a system-level perspective. We identify four main capabilities critical for enhancing resilience. By highlighting the significance of SC coordination, we examine how businesses can protect themselves against unexpected challenges and retaining their competitive edge. Hence, it can be proposed that coordination between SC members is a vital component in achieving SCRE (Herrera et al., 2022; Kumar et al., 2022a, 2022b). A well-coordinated system is more likely to be resilient and robust, as it can respond more quickly and effectively to disruptions and stressors. Likewise, a resilient and robust system can help maintain coordination and functioning effectively even under adverse conditions. The three concepts are interdependent and mutually reinforcing, each contributing to a system's overall effectiveness and stability. Hence, we postulate the following hypothesis:

Hypothesis H4: Supply Chain Coordination is positively related to Supply Chain Resilience.

Hypothesis H5: Supply Chain Robustness is positively related to Supply Chain Resilience.

IoT-BDA

To improve knowledge exchange, explicit knowledge can be effectively utilized through the aid of compatible IT services and advancements such as IoT and big data analytics (Liu et al., 2013). Moreover, IoT-BDA enables firms to exchange and process knowledge with low technological constraints, thus allowing them to compete better in the market. However, the literature on the effect of IoT and BDA on SCFP has been sparse (Aryal et al., 2018; Edwin Cheng et al., 2021). Previous authors have extensively focused on BDA (Gawankar et al., 2020) and emphasized its role in providing overall better organizational performance. On the other hand, IoT has been explored only to a limited extent, with only a few studies discussing how well a firm's governance systems can accommodate IoT-BDA, and assimilation concerns how well IoT-BDA has diffused across the firm's process (Gunasekaran et al., 2017). Implementing IoT and leveraging Big Data Analytics in the SC can lead to increased resilience and adaptability, making the SC more robust and better equipped to handle disruptions and challenges (Acciarini et al., 2023). SC Robustness and IoT-BDA highlights the value of integrating these technologies into the SCM process, enabling businesses to build a more resilient and efficient SC ecosystem.

BDA is expected to effectively restructure SC operations (Zhan & Tan, 2020). Data-driven decision-making support systems in SCs help to achieve financial goals by maximizing resource utilization through improved coordination and cooperation among stakeholders (Edwin Cheng et al., 2021; Gawankar et al., 2020). Furthermore, BDA is essential for monitoring and tracking social elements in multi-tier SCs (Venkatesh et al., 2020). Moreover, Barbeito-Caamao and Chalmeta (2020) contend that BDA facilitates the management of different stakeholder data, the extraction of social network insights, and the creation of value for all parties. Furthermore, according to Khan et al. (2021), businesses can use BDA methodologies to model, forecast, and unlock the behavior of social stakeholders including employees, government agencies, and NGOs, allowing for the identification of their tendencies and any potential social concerns that might occur. SC robustness provides survivability to an SC from various types of risks, such as supply, operation, demand, and security (Zhang & Wang, 2011). IoT-BDA can significantly contribute to increasing the SC Resilience. A more resilient SC can better absorb shocks, recover faster from disruptions, and adapt to changing market dynamics, ultimately improving overall business performance and customer satisfaction. By improving data visibility, decision-making processes, and collaboration among stakeholders, IoT-BDA can support SC coordination, efficiency, and responsiveness. However, well-informed decisions are necessary for a firm or SC to have better chances of survival, which can only be achieved with technological advancements. In this study, we follow the generalizations and hypotheses made in previous research with empirical research, and given these arguments, we develop the following hypotheses:

Hypothesis H6: Supply Chain Robustness is positively related to IoT-BDA.

Hypothesis H7: Supply Chain Resilience is positively related to IoT-BDA.

Hypothesis H8: Supply Chain Coordination is positively related to IoT-BDA.

Supply Chain-Firm Performance

Supply Chain-Firm Performance (SCFP) reveals how well a firm's SC fulfills its objectives compared to its prime opponents (Cao & Zhang, 2011; Lu et al., 2018b; Pahi et al., 2023). This study measured performance by sales growth, profit margin, return on investment (ROI), and growth in ROI. Previous research has widely used these measures because of their broad applicability across different business verticals (Liu et al., 2013). Manufacturing firms have immense distress in handling big data due to swiftly aggregating global data and related complexity (Kafetzopoulos et al., 2023). This demands advances in IT that can help a firm to handle such issues with great ease; hence IoT-BDA will help a firm to perform better in a competitive world where technology can help a firm to make well-versed choices, handle and mitigate threats, enhance and making effective operations even in disruptions (Moktadir et al., 2019). IoT devices have the capability to offer up-to-the-minute information regarding inventory levels, product status, and transportation conditions, thereby facilitating enhanced tracking and surveillance of SC operations. This helps in identifying and resolving issues promptly, leading to improved performance. IoT-BDA can improve customer experience by providing timely updates on order status, delivery times, and product quality. Satisfied customers are more likely to become repeat buyers and advocate for the brand, positively impacting the firm's performance.

Although extant academic literature has offered many examples of successful IoT-BDA implementation, practitioners are hesitant to regularly assign resources to BD (El-Kassar & Singh, 2019). It is empirically tested that business process models for significant data initiatives are contributing factors supporting resource management and better firm performance. Gunasekaran et al., (2017) and Mikalef et al. (2020) emphasize the significance of the IoT in fostering capabilities, leading to the enhancement of overall firm performance and, consequently, the attainment of a CA. Timely adoption of necessary IT advancements orchestrates resources and creates capabilities (El-Kassar & Singh, 2019). As IoT-BDA technologies remain integral to IT capabilities, the SC should concentrate on cultivating a distinctive BDA capability. This unique BDA capability aims to improve the quality of decision-making by leveraging IoT-BDA to enhance overall SCFP. Conceptual model is highlighted in Fig. 1. Demographic profile is shown in Table 1.

Hypothesis H9: IoT-BDA is positively related to firm's Supply Chain Performance.

Measurement Model

In this research, sample p

articipants are assumed to have experience in SCM. However SC area was studied in Indian context as economic and social scenarios of western countries are different compared to India. India, among the South—Asian countries, is considered to be contributing significantly to the manufacturing industry. However, a significant portion of "Indian manufacturing units are unorganized and unregistered across the country," creating challenges in sampling for business research (Singh et al., 2013). The sampling design comprises the sampling frame, method, size, and unit of analysis. After compiling the list of professionals, a total of 490 individuals were initially approached to participate in the survey, with 180 agreeing to participate in face-to-face meetings after collecting samples, which included management development programs. Both snowball and judgmental sampling techniques were utilized to improve the response rate. The judgmental sampling method allowed researchers to directly target their specific population of interest, while snowball sampling enabled the identification of units of analysis through chain-referral sampling. However, it is important to note that snowball sampling may not always guarantee sample representativeness, and judgmental sampling could introduce human error, leading to researcher bias. The participants were asked to provide references of individuals working in the SC area, resulting in 17 additional samples from the snowball sampling method. Additionally, a database of SC managers was created using LinkedIn professional groups, and 40 professionals were added to the network and requested to respond to the questionnaire. Eventually, 20 responses were received from LinkedIn.

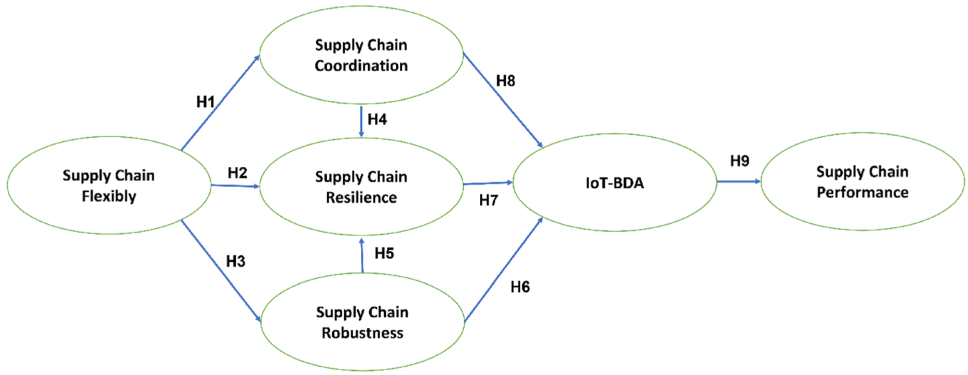

Fig. 1 Theoretical model

Table 1 Demographic profile

Items		N(217)	%
Age	25–35	65	29.95
	36–55	111	51.15
	56–75	41	18.89
	Total	217	
Gender	Male	145	66.82
	Female	72	33.17
	Total	217	
Educational qualification	UG	78	36
	PG	124	57.14
	PhD	15	6.9
	Total	217	
Years of experience	0–5	35	16.12
	5–10	64	29.49
	10–15	103	47.46
	15–20	15	6.9
	Total	217	

Determining an appropriate sample size proved to be a challenging step, involving various qualitative and quantitative considerations. In total, 232 samples were collected, and out of these, 217 samples were deemed useful for the research. The response rate was calculated at 39.4% (217 out of 550 contacted individuals). We employed an exploratory factor analysis with varimax rotation to gauge the initial measurement scale (refer to Table 7) (Sharma et al., 2023d; Singh et al., 2024). Additionally, we utilized the Kaiser–Meyer–Olkin (KMO) method and Bartlett's sphericity test to evaluate the suitability of the factor analysis. The KMO test confirmed that the overall sampling was adequate, yielding a value of 0.897 (greater than the recommended threshold of 0.50). Bartlett's test of sphericity further validated the instrument's credibility, yielding a significant result (8356.63, df = 595, $p < 0.001$) (see Table 8).

This study utilized a three-stage approach to assess reliability, validity, and unidimensionality (Hair et al., 2014). To establish reliability, we calculated the average correlation between items on the scale (see Table 2), and all variables had a Cronbach's alpha value above the accepted cutoff of 0.7 (Hair et al., 2014). In relation to validity, we evaluated both convergent and discriminant validity. The standardized loadings of each item were found to be higher than 0.5 (as shown in Table 2), indicating satisfactory evidence for convergent validity. Additionally, the construct reliability (CR) surpassed 0.7, and the average variance extracted (AVE) exceeded 0.5, further supporting the convergent validity. To test discriminant validity, we followed Fawcett et al. (2011), which suggests that "all items should have higher loadings on their assigned constructs than on any other constructs." Moreover, we ensured that the square root of the AVE for

Table 2 Measurement model results

Construct	Measurement Items	Loading	α	CR	AVE
Supply Chain Resilience	SCRE1	0.819	0.942	0.942	0.701
SCRE	SCRE2	0.884			
	SCRE3	0.911			
	SCRE4	0.925			
	SCRE5	0.841			
	SCRE6	0.758			
	SCRE7	0.697			
Supply Chain-Firm Performance	SCFP1	0.645	0.934	0.935	0.677
SCFP	SCFP2	0.856			
	SCFP3	0.896			
	SCFP4	0.913			
	SCFP5	0.902			
	SCFP6	0.839			
	SCFP7	0.661			
Supply Chain Flexibility	SCFL1	0.763	0.837	0.846	0.526
SCFL	SCFL2	0.741			
	SCFL3	0.773			
	SCFL4	0.751			
	SCFL5	0.581			
Internet of things and Big Data	IOTBDA1	0.637	0.914	0.915	0.607
IOT-BD	IOTBDA2	0.845			
	IOTBDA3	0.761			
	IOTBDA4	0.759			
	IOTBDA5	0.851			
	IOTBDA6	0.872			
	IOTBDA7	0.7			
SCRO	SCRO1	0.65	0.81	0.9	0.702
	SCRO2	0.53			
	SCRO3	0.643			
	SCRO4	0.55			
	SCRO5	0.415			
Supply Chain coordination	SCCO1	0.728	0.819	0.819	0.531
SCCO	SCCO2	0.764			
	SCCO3	0.71			
	SCCO4	0.712			

each variable was greater than any correlation estimate (as presented in Table 2). Based on these results, we can confidently affirm that there is ample evidence to substantiate the discriminant validity of the measures employed in the study. To evaluate the unidimensionality of our conceptual model, we assessed the overall model fit using different criteria recommended by Hu and Bentler (1999) and Chen and Paulra (2004) (see Table 9 in Appendix A). The results suggest that the constructs exhibit unidimensionality (Table 3).

Common Method Bias

Primary data were collected from one source, so the possibility of common method bias is high (Podsakoff & Organ, 1986). There could be sources like consistency motif and acquiescence biases for common method biases (Dubey et al., 2017). Therefore, we seriously considered this issue and minimized common method biases by including various independent, moderating, and dependent variables. However, we performed Harman's single-factor analysis on all measurement items (Harman, 1967). If all

Table 3 Discriminant validity

	SCRO	SCFP	SCRE	IoT-BDA	SCFL	SCCO
SCRO	0.781					
SCFP	− 0.145	**0.823**				
SCRE	0.079	− 0.135	**0.837**			
IOTBDA	0.196	− 0.286	0.339	**0.779**		
SCFL	0.210	− 0.144	0.555	0.429	**0.725**	
SCCO	0.205	− 0.183	0.292	0.392	0.303	**0.729**

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

the items across variables load on one factor, common method biases would be available. An exploratory factor analysis was executed largest factor contributed to 25.88 percent of the variance (Table 6) (Appendix A).

Hypothesis Testing

The entire hypothesis mentioned in Table 4 was obtained from AMOS 20. We have presented the corresponding *p* values and path coefficients for the model in Table 4. The links SCFL → SCCO ($p < 0.05$), SCFL → SCRE (beta = 0.53, $p < 0.05$), SCFL → SCRO ($p < 0.05$), SCRE → IOT-BDA ($p < 0.05$), SCCO → IOT-BDA ($p < 0.05$) are positively related whereas IOT-BDA → SCFP ($p < 0.05$) is negatively related.

Coordination among SC partners improves resilience (Tarigan et al., 2021). When there is effective communication and cooperation, partners can support each other during challenging times, making it easier to enhance SCFP (Brandon-Jones et al., 2021). A flexible SC is better equipped to adapt and recover from disruptions, making it more resilient overall. An integrated approach that incorporates flexibility, coordination, resilience, and robustness will lead to a stronger and more reliable SC that can thrive in a dynamic and challenging business environment. Therefore, we can claim from beta values and corresponding *p* values that hypotheses H1, H2, H3, H7, H8, and H9 were supported. Further, we tested mediating effect of coordination, resilience, and robustness between SCFL and IOT-BDA to achieve performance. The mediating analysis's outcome shows a full mediation between SCFL, SCRE, IOT-BDA, and SCFP, as shown in Table 5.

This study explains how SCFL influences SCCO, SCR, and SCRB in improving SCFP. The study also investigates the role of SCRE with IOT-BDA. The study's results demonstrate a noteworthy influence of IoT-BDA adoption on SC performance. It indicates that implementing IoT-BDA enhances a firm's efficiency and cost-effectiveness by eliminating wasteful practices. Additionally, the technology offers increased visibility for firms to map their operations and SC activities. The use of IoT and BDA provides precise information when uncertain events arise, allowing companies to make timely decisions to manage uncertainties and disruptions effectively. The study's outcome underscores the significance of various critical dimensions within the SC for achieving overall performance improvements. Hence, this study confirms that SCCO, SCRE, and SCRB is a vital set of dimension to enhance SCFP.

Table 4 Path coefficients, *t*-statistics, and *p* values

Hypotheses	Path	*P* values	Decision
H1	SCFL → SCCO	***	Accepted
H2	SCFL → SCRE	***	Accepted
H3	SCFL → SCRO	***	Accepted
H4	SCCO → SCRE	0.015	Not Accepted
H5	SCRO → SCRE	0.239	Not Accepted
H6	SCRO → IOTBDA	0.017	Not Accepted
H7	SCRE → IOTBDA	***	Accepted
H8	SCCO → IOTBDA	***	Accepted
H9	IOTBDA → SCFP	***	Accepted

Significant at P value < 0.05; t-statistics > 1

Table 5 Results of mediation effect

Relationship	Direct effect	Indirect effect	Result
SCFL→SCRO→SCRE→IOTBDA →SCFP	0.499	0.001	Full mediation
SCFL→SCRE→IOTBDA→SCFP	0.499	− 0.043	Full mediation
SCFL→SCRO→IOTBDA→SCFP	0.499	− 0.011	Full mediation
SCFL→SCCO→IOTBDA→SCFP	0.499	− 0.033	Full mediation
SCFL→SCCO→SCRE→IOTBDA →SCFP	0.499	− 0.003	Full mediation

Significant at P value < 0.1

Conclusion

The pandemic underscored the vulnerability of global SCs and the imperative for companies to enhance resilience and adaptability in the face of unexpected disruptions (Agrawal & Pingle, 2020). This paper investigated the mediating role of resilience between coordination and IoT-BDA, examining the relationships among coordination, robustness, and IoT-BDA. The major contribution of this study lies in its application of a technology perspective and various critical dimensions of the SC to enhance SCFP. To attain this goal, a conceptual model was formulated using RBV and DCT, illustrating mediating variables such as resilience, coordination, and robustness between flexibility and IoT-BDA. The results reveal the crucial role of coordination in the effective implementation of IoT-BDA, demonstrating that the proper adoption of IoT-BDA ultimately enhances a firm's overall performance. Therefore, our findings suggest that organizations need proper coordination among diverse SC partners and suitable resilience strategies to enhance SCFP. This study makes several contributions, including exploring the potential use of dynamic capability theory in the context of SC resilience and IoT-BDA, and investigating the relationship between coordination, resilience, and IoT-BDA. We employed RBV and DCT to connect flexibility, robustness, resilience, and coordination, identifying a statistically significant positive relationship between coordination, resilience, robustness, IoT-BDA, and performance. Moreover, our research outcomes indicate a complete mediation of resilience between flexibility and IoT-BDA.

The research offers practical ideas for enhancing SC resilience and robustness in the Pacific region post-pandemic, suggesting that organizations adopt robust resilience strategies to counter the negative effects of COVID-19 on the SCs. Our findings reveal that coordination in SCs plays a crucial role in connecting flexibility and IoT-BDA, emphasizing the importance of collaboration among partners to enhance performance. Resilience also proves significant in the relationship between coordination and IoT-BDA, offering crucial insights for SC managers and practitioners. The comprehensive role of resilience, particularly between flexibility, coordination, and IoT-BDA, underscores the need for consistent evaluation and improvement of resilience strategies for better performance. SC practitioners should ensure top management implements effective strategies for successful IoT-BDA implementation and focus on enhancing IoT-BDA and SC performance by incorporating coordination, robustness, and resilience.

This study has limitations that present opportunities for further investigation. Firstly, it focuses on a conceptual model within a single country, suggesting the need for future studies across multiple countries. The lack of empirical research on the interplay among coordination, resilience, robustness, IoT-BDA, and performance presents a gap for future exploration. Industry professionals can leverage our model for agile SC capabilities, particularly in addressing challenges akin to those during the COVID-19 pandemic. Methodologically, considering a hybrid approach like MCDM alongside Structural Equation Modeling could provide richer insights. Gathering data from diverse sectors for empirical validation and exploring different antecedents of SCRE and IoT-BDA are avenues for future research. Additionally, both conceptual and empirical investigations into the antecedents and consequences of SCFP could be explored. While this study utilizes RBV and DC theories to emphasize SCRE, there may be other theories contributing to enhancing SCFP through SCRE.

Appendix A

See Tables 6, 7, 8 and 9.

Table 6 Herman's single factor test (total variance explained)

Component	Initial Eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	9.061	25.889	25.889	9.061	25.889	25.889
2	4.663	13.323	39.212			
3	3.293	9.410	48.621			
4	2.165	6.184	54.806			
5	2.004	5.725	60.531			
6	1.727	4.934	65.465			
7	1.060	3.028	68.493			
8	.768	2.194	70.687			
9	.737	2.105	72.792			
10	.701	2.003	74.795			
11	.659	1.884	76.679			
12	.612	1.749	78.428			
13	.602	1.721	80.149			
14	.590	1.686	81.835			
15	.551	1.574	83.409			
16	.517	1.477	84.886			
17	.472	1.348	86.234			
18	.444	1.270	87.504			
19	.430	1.227	88.731			
20	.401	1.146	89.877			
21	.372	1.064	90.941			
22	.352	1.005	91.946			
23	.344	.981	92.927			
24	.310	.887	93.814			
25	.306	.875	94.689			
26	.279	.798	95.487			
27	.257	.735	96.222			
28	.254	.726	96.948			
29	.228	.652	97.600			
30	.206	.588	98.188			
31	.167	.478	98.665			
32	.143	.410	99.075			
33	.121	.347	99.422			
34	.105	.299	99.721			
35	.098	.279	100.000			

Extraction Method: Principal Axis Factoring. Percentage of Variance is 25.88 which is below 50% and satisfies that there is no common method bias in the data

Table 7 Rotated component matrix

	Component					
	1	2	3	4	5	6
SCRE4	.884					
SCRE3	.871					
SCRE5	.854					
SCRE2	.827					
SCRE1	.820					
SCRE6	.794					
SCRE7	.748					
SCFP3		.907				
SCFP5		.892				
SCFP4		.889				
SCFP2		.882				
SCFP6		.850				
SCFP1		.709				
SCFP7		.696				
IOTBDA6			.854			
IOTBDA2			.843			
IOTBDA5			.830			
IOTBDA3			.794			
IOYBDA4			.741			
IOTBDA7			.685			
IOTBDA1			.679			
SCFL4				.779		
SCFL3				.746		
SCFL2				.739		
SCFL1				.735		
SCFL5				.656		
SCCO1					.790	
SCCO2					.786	
SCCO3					.768	
SCCO4					.742	
SCRO3						.720
SCRO2						.654
SCRO4						.636
SCRO1						.631
SCRO5						.563

Rotation converged in 6 iterations

Table 8 KMO and Bartlett's test

KMO measure of sampling adequacy		.897
Bartlett's Test of Sphericity	Approx. Chi-Square	8356.635
	Df	595
	Sig	.000

Table 9 Model fit summary

Model	NPAR	CMIN	DF	*P*	CMIN/DF
CMIN					
Default	114	1127.647	551	.000	2.047
Saturated	665	.000	0		
Independence	70	8815.491	595	.000	14.816

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Baseline comparisons					
Default	.872	.862	.930	.924	.930
Saturated	1.000		1.000		1.000
Independence	.000	.000	.000	.000	.000

Model	PRATIO	PNFI	PCFI
Parsimony-adjusted measures			
Default	.926	.808	.861
Saturated	.000	.000	.000
Independence	1.000	.000	.000

Model	RMSEA	LO 90	HI 90	PCLOSE
RMSEA				
Default	.053	.048	.057	.149
Independence	.192	.188	.195	.000

Model	AIC	BCC	BIC	CAIC
AIC				
Default	1355.647	1379.788		
Saturated	1330.000	1470.824		
Independence	8955.491	8970.314		

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Declarations

Conflict of interest The authors confirm that they have no conflicts of interest.

Ethical Approval This research does not cover any studies with human participants performed by any of the authors. Data will be made available upon request.

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Key Questions

The main question addressed in this study is how supply chain flexibility (SCFL) impacts supply chain coordination (SCCO), supply chain resilience (SCRE), and supply chain robustness (SCRB), ultimately contributing to the enhancement of supply chain performance (SCFP). The study aims to understand the intricate relationships between these factors and their combined influence on overall supply chain perfromance.

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Nishant Agrawal is a faculty member at ICFAI Business School, Ahmedabad, and has a PhD in operations management from Nirma University, Ahmadabad. He has ten years of academic/research experience with around 30 months of full-time and part-time corporate expertise. He is a corporate trainer for the topic Lean Six Sigma as well. He worked with renowned companies like Flipkart and Reliance Digital. He has published research papers in Annals of Operations Research, Technovation, Business Strategy and the Environment, Journal of Cleaner Production, Resources Policy etc. He has presented various research papers at national and international conferences, including IIM A, IIM B, IIM Indore, S P Jain, K J Somaiya, NMIMS, etc. He got best research paper award from Symbiosis, NMIMS, Chitkara University, Nirma University etc.

Mahak Sharma is currently an Assistant Professor at the University of Twente. Her primary focus is on sustainability, circular economy, and digital transformation, with a vision of developing new strategies and approaches toward sustainable and circular production, consumption, and waste management. She is a doctorate from the Indian Institute of Management (IIM) (Formerly-National Institute of Industrial Engineering (NITIE)), India. She holds a Master's and a Bachelors in Computer Science and Engineering. She is one of the few female recipients of POMS Honorable Mention for research work. She has publications in various reputed journals and conferences including Annals of Operation Research, Technological Forecasting and Social Change, IEEE Transactions of Engineering Management, Journal of Cleaner Production. She is on the Editorial Review Board of prestigious journal IEEE Transactions of Engineering Management. She also has over six years of industry experience in product management and software development.

Rakesh D. Raut is an Associate Professor of Operations and Supply Chain Management at the Indian Institute of Management (IIM), Mumbai. Rakesh D. Raut received his Post-Doctoral Fellow from EPFL, Switzerland, and Fellowship (Ph.D.) from the Indian Institute of Management (IIM), Mumbai (earlier known as the National Institute of Industrial Engineering (NITIE), Mumbai. He has more than nine years of work experience in industry and academic institutions. Before joining NITIE, he worked as an Assistant Professor at IMT, Nagpur, Dubai, and Symbiosis Centre for Management and Human Resource Development (SCMHRD), Pune. His research interest includes Industry 4.0, Cloud Computing Adoption, Cloud-IoT Adoption, Big Data Analytics, Green/Sustainable Supply Chain Management, He has co-authored several research items in peer-reviewed international journals such as International Journal of Production Research, International Journal of Production Economics, Transportation Research Part E: Logistics and Transportation Review, Industrial Marketing Management(IIM), Technovation, Journal of Cleaner Production, Renewable Energy, Annals of Operations Research, Business Strategy and the environment, etc.

Sachin Kumar Mangla is working in the field of Green and Sustainable Supply Chain and Operations; Industry 4.0; Circular Economy; Decision-Making and Simulation. He has a teaching experience of more than five years in Supply Chain and Operations Management and Decision-Making, and currently associated in teaching with various universities in UK, Turkey, India, China, France, etc. He is the director of Research Centre for "Digital Circular Economy for Sustainable Development Goals (DCE-SDG), O.P. Jindal Global University, India. He is committed to do and promote high quality research. He has published/presented several papers in repute UTD24/FT50/ABS 4/ABDC A* journals (Production and Operations Management (POM) Journal of Business Research; International Journal of Production Economics; International Journal

of Production Research; Computers and Operations Research; Production Planning and Control; Business Strategy and the Environment;; Annals of Operations Research; Transportation Research Part-D; Transportation Research Part-E; Renewable and Sustainable Energy Reviews; Resource Conservation and Recycling; Information System Frontier; Journal of Cleaner Production; Management Decision; Industrial Data and Management System) and conferences (POMS, SOMS, IIIE, CILT – LRN, MCDM, GLOGIFT). He has an h-index 70, i10-index 150, Google Scholar Citations of 15,000. He is involved in several editorial positions and editing couple of Special issues as a Guest Editor in top tier journals. Currently, he is working as an Associate Editor at Journal of Cleaner Production, International Journal of Logistics Management, Sustainable Production and Consumption, Corporate Social Responsibility and Environmental Management, and IMA Journal of Management Mathematics journals. He is also involved in several research projects on various issues and applications of Circular economy, Industry 4.0 and Sustainability. Among them, he contributed to the knowledge-based decision model in "Enhancing and implementing knowledge-based ICT solutions within high risk and uncertain conditions for agriculture production systems (RUC-APS)", European Commission RISE scheme. Recently, he has also received a grant as a PI from British Council – Newton Fund Research Environment Links Turkey/UK – Circular and Industry 4.0 driven solutions for reducing food waste in supply chains. He is also working in several projects on Food Waste and Circular Economy and Industry 4.0 issues, sponsored by AICTE, ICSSR, Government of India. He received project funding for Food Waste Management in Circular Economy from the USERC, Government of India. He has also won the first prize for the prestigious Basant Kumar Birla Distinguished Scholar Award 2021. He was ranked 404 in the world and 10 in United Kingdom and was recognized with 2022 Rising Star of Science Award by Research.com. He was also ranked among the top 2% scientists in the world by the Stanford University. This year, in 2023, has also bene included in the Clarivate™ list of the top 7,125 global research scientists (1% top scientists in social science research) and social scientists (1 in 1000) who have demonstrated significant and broad influence in their field(s) of research. Recently, he also been awarded as a High-End Foreign Expert Talent Grant from Ministry of Science and Technology, China. He is also the member of NWO—Dutch Research Council—Circular Economy Committee. He is also an active member of The Future Earth Systems of Sustainable Consumption and Production Knowledge-Action Network (SSCP KAN).

Sobhan Arisian is the founder coordinator of the Logistics and Supply Chain Management program at La Trobe Business School. As an applied operations researcher, Sean has a special interest in modeling and solving practical logistics and supply chain problems. His multidisciplinary research addresses issues related to security and resiliency at the global supply chain/international trade interface. Sean's research has been published in leading journals (UTD24 and ABDC A*/A), including Production & Operations Management, IEEE Transaction on Systems, Man, and Cybernetics, Transportation Research (Part E), International Journal of Production Economics, and International Journal of Production Research among others. Sean has close ties with the local industry and international scholars, and has successfully established a strong collaboration network. Sean is a member of the Editorial Advisory Board for "Transportation Research Part E" and also serves as an external assessor for the National Research Grants Council (Hong Kong).