A Leagile Supply Chain Model for the Effective Mitigation of Sudden Risks

Towfique Rahman
UTS Business School, University of Technology Sydney, Sydney, Australia
Towfique.Rahman@uts.edu.au

Sanjoy Kumar Paul
UTS Business School, University of Technology Sydney, Sydney, Australia
Sanjoy.Paul@uts.edu.au

Abstract

The leagile supply chain (SC) approach, merging lean and agile strategies, has gained traction within the dynamic landscape of food manufacturing industries. By combining the efficiency of lean practices with the adaptability of agile principles, leagile SCs adeptly handle both regular operations and disruptions. This study explores the functioning of leagile SCs in various scenarios, highlighting their efficacy in efficient inventory management and rapid response to market changes, i.e., demand surges. Additionally, it discusses potential avenues for future research, including technological advancements and sustainable practices, aiming to reshape the food manufacturing SC landscape for enhanced industry standards and improved customer experiences.

Keywords
Supply chain, lean; agile, simulation, optimization and food industry.

1. Introduction
In the ever-evolving realm of food manufacturing, the emergence of the leagile (lean and agile) supply chain (SC) strategy represents a transformative approach that seamlessly amalgamates the efficiency of lean strategies with the adaptability of agile frameworks. As businesses experience both normal operational scenarios and disruptive market fluctuations, this hybrid strategy has garnered significant attention for its potential to offer a comprehensive solution to the challenges faced by the industry (Ivanov, 2021). This paper studies the importance of the leagile SC, shedding light on its principles and impact on food manufacturing companies, while also outlining future avenues for research within this dynamic field. The leagile SC strategy finds its roots in the complementary nature of lean and agile philosophies. Lean strategies, geared towards minimizing waste and optimizing resources, are adept at streamlining production processes in a stable environment (Dolgui et al., 2018). Conversely, agile principles, rooted in flexibility and responsiveness, empower businesses to swiftly adapt to unforeseen disruptions. The synthesis of these approaches positions leagile SCs as adaptable and efficient, equipping businesses to address both routine demand fluctuations and sudden market fluctuations effectively (Chowdhury et al., 2021).

Two pivotal research questions arise in exploring the leagile SC strategy's potential and implementation. Firstly, how does the integration of postponement and just-in-time inventory strategies contribute to optimizing production processes and customer satisfaction in food manufacturing companies? This question delves into how leagile strategies align production with real-time demand, leading to reduced lead times, efficient inventory management, and timely customer fulfillment. Secondly, as leagile SCs prove their strength and resilience during disruptions, what strategies can be harnessed to enhance their effectiveness further? Investigating this question entails exploring cutting-edge methodologies like simulation and optimization, which can ensure transparency, traceability, and risk management.
In the subsequent sections of this paper, we will review the leagile SC strategies, sudden risk and strategies to mitigate them along with research gaps and problem statement in section 2, present model formulation and proposed strategies in section 3, describe results and discussions in section 4 and conclude with future research directions in section 5.

2. Literature review

We review lean and agile supply chain (SC), the main component of leagile SC, from literature in this section and sudden risk within SCs. Mitigation strategies for reducing the risks in SCs will also be discussed in this section. Finally, research gaps and problem statements are highlighted based on the review.

2.1. Lean and agile SCs

A lean and agile SC represents a transformative approach to managing the intricate flow of resources, materials, and information across organizational operations. This strategy harmonizes the core principles of lean manufacturing and agile strategy, resulting in a dynamic, resilient, and efficient SC ecosystem (Ivanov, 2021). At its core, lean thinking revolves around the reduction of waste and the pursuit of operational excellence. Initially conceived in the context of manufacturing, lean principles seek to eliminate non-value-added activities, overproduction, inventory excess, waiting times, and defects (Yılmaz et al., 2023). When applied to the broader SC, these concepts emphasize the optimization of inventory management, precise demand forecasting, and a relentless commitment to continuous improvement. By trimming unnecessary processes and focusing on value creation, companies can enhance resource utilization, minimize lead times, and elevate overall operational efficiency. Complementing the lean philosophy, agile methodology originated in software development and has found substantial relevance in SC management (Tarafdar & Qrunfleh, 2017). As markets grow increasingly complex and unpredictable, the agile approach champions flexibility, adaptability, and rapid response. Agile principles encourage collaboration, cross-functional teamwork, and iterative decision-making. This strategy empowers organizations to swiftly recalibrate strategies and operations based on real-time data and customer feedback. It enables them to exploit emerging opportunities and navigate unforeseen disruptions with agility and precision (Hasani, 2021).

The integration of lean and agile principles within the SC domain gives rise to a hybrid model that capitalizes on the synergies between efficiency and responsiveness. This holistic approach acknowledges the dual nature of SC environments, encompassing both routine processes and unexpected disturbances (Golan et al., 2020). By harmonizing the lean emphasis on optimization with the agile emphasis on flexibility, businesses can attain equilibrium, fostering superior customer satisfaction while concurrently refining operational costs. Implementing a lean and agile SC necessitates a cohesive set of strategies. First, accurate demand forecasting and efficient inventory management prevent overproduction or understocking. Second, fostering collaborative partnerships with suppliers, distributors, and stakeholders facilitates seamless communication and synchronization, reducing lead times and enhancing efficiency. Third, assembling cross-functional teams embodies the agile spirit of swift problem-solving and innovation, which is particularly beneficial in dynamic SC scenarios (Um & Han, 2021).

Continuous improvement, a main principle of both lean and agile strategies, ensures that SC processes remain adaptable and efficient over time. Advanced technologies such as data analytics, the Internet of Things (IoT), and artificial intelligence act as enablers, providing real-time data visibility necessary for data-driven decisions and rapid responses to emerging challenges. Furthermore, agile practices empower SCs to anticipate and mitigate risks proactively. Establishing contingency plans and proactive strategies enhances a SC's resilience, allowing it to maintain operations even in the face of unforeseen events. Therefore, a lean and agile SC amalgamates lean manufacturing's emphasis on waste reduction and efficiency with an agile strategy's focus on flexibility and responsiveness (Hsu et al., 2021). This integration results in a SC network that can adeptly navigate modern complexities, delivering customer value, reducing lead times, and achieving operational excellence. By creating an environment where efficiency and adaptability coexist, organizations can position themselves competitively in a rapidly evolving business landscape (Can Saglam et al., 2020).

2.2. Sudden risks in SCs

Sudden risks within SCs represent significant and unpredictable disruptions that can profoundly impact operations and overall business continuity. These risks can encompass a range of factors, including natural disasters, geopolitical conflicts, economic downturns, technological failures, and unexpected regulatory changes (Razavian et al., 2021). The unique characteristic of these risks lies in their abrupt nature, often catching organizations off guard and necessitating immediate responses. Natural disasters such as earthquakes, hurricanes, and floods can devastate key SC nodes, disrupting transportation, manufacturing, and distribution activities. Geopolitical tensions or conflicts can lead to sudden trade restrictions, border closures, or SC disruptions, affecting sourcing strategies and lead times. Economic downturns can cause demand fluctuations, sudden shifts in consumer behavior, and SC interruptions due to financial constraints (Dolgui & Ivanov, 2020). Technological failures in critical infrastructure or IT systems can halt operations and lead to data breaches, causing cascading disruptions across the SCs. Unforeseen regulatory changes related to product standards or trade agreements can necessitate swift adjustments to operations and sourcing strategies (Chowdhury et al., 2021).

The impact of sudden risks extends beyond immediate operational challenges. SCs can experience increased costs, reduced revenue, reputational damage, and customer dissatisfaction. To effectively manage these risks, businesses need to adopt proactive measures. Developing robust risk assessment frameworks, diversifying suppliers and sourcing locations, maintaining a flexible and adaptable SC network, and investing in technologies such as real-time tracking and analytics are critical steps. Furthermore, cultivating strong relationships with suppliers and partners fosters collaboration and information-sharing, enabling quicker responses to sudden risks. Establishing contingency plans, conducting scenario planning, and regularly testing these plans through simulations can enhance a SC's resilience. Integrating agile strategies and fostering a culture of adaptability within the organization can empower teams to adjust to unexpected challenges swiftly (Paul et al., 2018). Sudden risks within SCs pose substantial threats due to their sudden and unforeseen nature. These risks can stem from natural disasters, geopolitical conflicts, economic shifts, technological failures, and regulatory changes. Managing such risks requires a proactive approach involving risk assessment, diversification, flexibility, collaboration, and adopting advanced technologies. By fortifying SCs against sudden disruptions, organizations can enhance their ability to navigate uncertainties and maintain operational stability (Paul & Chowdhury, 2020a).

2.3. Mitigation strategies for managing risks in SCs

Mitigation strategies are pivotal for reducing risks within SCs and ensuring sustained operational resilience. These strategies encompass a range of proactive measures to identify, address, and minimize potential disruptions that could impact the flow of resources and information. Firstly, an integral step is rigorous risk assessment and meticulous planning. By evaluating vulnerabilities across the SC network, organizations can systematically prioritize potential risks based on their potential impact and likelihood. This assessment guides the creation of comprehensive contingency plans, enabling swift and effective responses in the event of disruptions (Rahman, Taghikhah, et al., 2021). Diversification emerges as a critical strategy in risk mitigation. Overreliance on a single supplier or sourcing location increases exposure to disruptions. By cultivating relationships with multiple suppliers and exploring alternative sourcing options, companies can minimize the impact of unexpected events from a single source. This approach enhances SC flexibility and ensures continuity in the face of supply-side challenges (Rahman et al., 2022).
SC visibility, facilitated by advanced technologies, plays a pivotal role. Real-time tracking, Internet of Things (IoT) sensors, and data analytics provide unparalleled insights into the movement of goods, allowing organizations to detect disruptions early and make informed decisions swiftly. This level of visibility empowers proactive risk management and facilitates accurate response strategies (Paul et al., 2021). Collaborative relationships among SC partners are indispensable. Transparent and open communication channels enable the early identification of potential risks, fostering cooperation in developing effective solutions. This collaborative approach enhances the collective ability to mitigate disruptions and maintain operational stability. Inventory optimization stands as another key strategy. Employing demand forecasting and lean inventory practices ensures inventory levels align with actual requirements. This approach minimizes excess inventory costs while enabling agility in adjusting to fluctuations in demand, reducing the impact of sudden supply disruptions (Paul & Chowdhury, 2020b).

Resilient network design involves creating redundancies and alternate routes within the SC. This strategy absorbs disruptions, preventing them from propagating through the entire network. By strategically implementing these redundancies, organizations can confine the impact of disruptions to isolated segments of the SC. Embracing technology remains pivotal. Blockchain technology enhances traceability, artificial intelligence aids in risk prediction, and cloud-based platforms facilitate real-time collaboration. These technological enablers provide valuable insights into potential risks and equip organizations with tools for proactive risk management (Rahman et al., 2021). Continuous monitoring, scenario planning, and regular improvement form the backbone of effective risk mitigation. Regularly reviewing and adjusting strategies based on emerging threats, market shifts, and lessons learned from past disruptions ensures the robustness of risk management approaches. Ultimately, well-trained and informed employees constitute the frontline of defense against risks. Equipping staff with the knowledge to recognize, respond to, and communicate potential disruptions is essential in ensuring a swift and coordinated response when challenges arise (Moktadir et al., 2018).

Therefore, comprehensive risk mitigation strategies involve a holistic approach that combines meticulous planning, diversification, technology adoption, collaboration, and continuous improvement. By integrating these strategies, organizations can enhance their capacity to navigate disruptions, maintain operational continuity, and safeguard customer satisfaction despite unforeseen events.

2.4. Research gaps and problem statement

Research in leagile SC and disruption management through network optimization models has yielded substantial progress, yet several key gaps warrant further investigation. Primarily, there is a need to develop a comprehensive and integrated framework that adeptly balances the trade-offs between lean and agile principles (Paul et al., 2021). This framework could explore how to seamlessly transition between these modes under varying disruption scenarios, enhancing decision-making flexibility. Additionally, while many existing studies assume static disruption scenarios, real-world disruptions are often dynamic and evolving. Investigating the creation of network optimization models that can adapt in real-time to changing disruption patterns could ensure more timely and effective response and recovery strategies. Furthermore, delving into multi-tier SC network optimization models under leagile strategies is an avenue worth exploring, as this could provide a more holistic understanding of disruption management across interconnected tiers. Addressing risk propagation and containment within such models, especially when disruptions have cascading effects, could offer insights into proactive risk management.

Integrating real-time data from IoT, AI, and data analytics sources into network optimization models is also an emerging gap. This could lead to the development of frameworks that enable accurate disruption prediction and responsive strategies based on real-time insights. Moreover, the human factor and organizational behavior remain underexplored in the context of leagile disruption management. Investigating how these elements influence the successful adoption of leagile strategies could contribute to more effective implementation. Bridging the gap between theory and practice through empirical validation is essential as well, where real-world case studies can substantiate the theoretical effectiveness of network optimization models in diverse industries. Lastly, embedding sustainability considerations within disruption management through leagile supply chains is an emerging dimension that requires exploration. Addressing these gaps can provide a more nuanced understanding of how leagile strategies can adeptly navigate disruptions and bolster operational resilience.

Considering the ramifications of abrupt disruptions in SC networks, our objective is to develop an optimized network within the SC that achieves the goals of optimizing operations while minimizing excess inventory in the production cycle to mitigate wastage. Simultaneously, this optimized SC network should possess the resilience to effectively respond to unforeseen risks within the SC, such as sudden spikes in demand. This can be achieved through the implementation of a two-fold strategy: a postponement approach and a just-in-time inventory policy. Our study focuses on a specific case company that operates in the food processing industry. This chosen context allows us to delve deeply into the dynamics of the SCs within the food processing industry and ascertain the feasibility and effectiveness of the proposed optimized network.

3. Model formulation and proposed strategies

We initially developed a leagile food processing and manufacturing SC using the anyLogistix software. This leagile SC incorporates multiple food item suppliers, with at least ten suppliers in proximity to five decentralized processing and manufacturing facilities across Australia. This renowned food processing and manufacturing company delivers packaged ready-to-eat meals to twenty retailers nationwide. The company employs several key strategies to uphold its leagile SC, such as:

1. Proximity of multiple suppliers to manufacturers
2. Implementation of decentralized manufacturing facilities
3. Adoption of a just-in-time production approach
4. Utilization of a production postponement strategy
5. Optimization of transportation routes to retailers

Drawing upon a comprehensive literature review and secondary data from market research, we gathered information about demand, manufacturing capacity, transportation capacity, facility costs, and packaged meal expenses. Subsequently, we conducted a simulation within the optimized network for a duration of one year to enhance predictive capabilities. The optimized SC network is presented in Figure 1, and the research framework for this study is depicted in Figure 2.

Our assessment of SC performance involves the evaluation of several key metrics, including demand fulfillment, aggregate production costs for both suppliers and manufacturers, fixed costs, and total transportation expenses from suppliers to manufacturers and from manufacturers to retailers. The overarching objective of this SC is to minimize the overall costs associated with the entire SC operations.

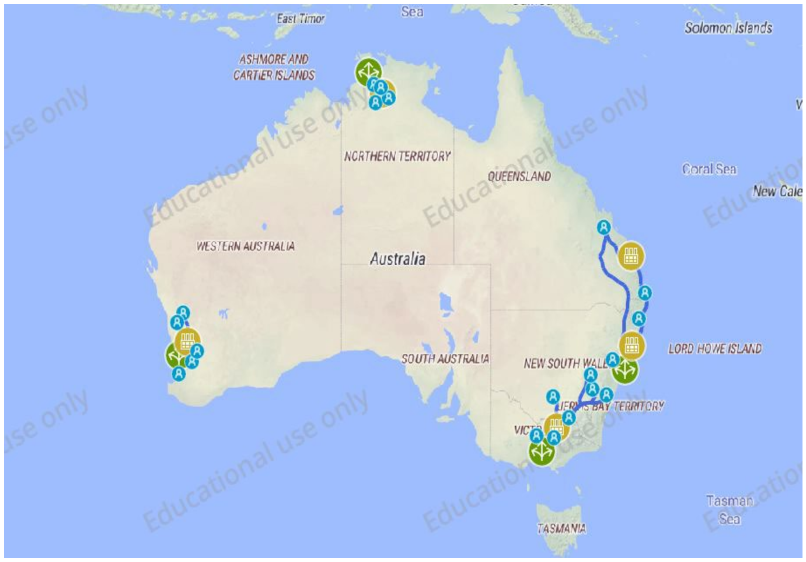

Figure 1. Optimized leagile SC network modeled in anyLogistix

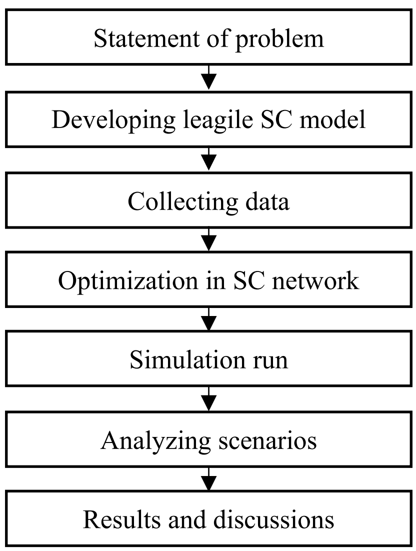

Figure 2: Research framework

4. Results and discussions

In this section, we analyze the functioning of the leagile SC for the food company under both normal and disrupted situations. This comprehensive evaluation provides a clearer insight into the operational performance of the leagile SC.

Normal scenario: In the normal scenario, when the business is running as usual, the leagile SC of the food manufacturing company is meeting the end customers' demand timely with the postponement and just-in-time inventory strategies of the manufacturing facilities. Retail demand at particular times is seen as normal and almost static in this normal scenario. Manufacturing facilities produce the end product, i.e., meal boxes from the raw materials from the suppliers as per the demand. They are maintaining the inventory as low as possible with safety stock as the product is perishable. With the postponement strategy and just-in-time inventory, they can fulfill the customer demand. For the production-related outputs, i.e., amount of meal boxes processed and production cost, please refer to Table 1. The outputs related to the demand fulfillment of the retailers are described in Table 2. Total supply chain costs in a normal scenario are presented in Table 3.

Table 1. Production related outputs in manufacturing facilities for the normal scenario

Manufacturing facility	End product	Amount	Production cost (AUD)
Manufacturer _ VIC	Meal box	26000	208000
Manufacturer _ QLD	Meal box	2000	16000
Manufacturer _ NT	Meal box	15600	124800
Manufacturer _ WA	Meal box	19500	156000
Manufacturer _ NSW	Meal box	14900	119200

Table 2. Demand fulfillment related outputs from retailers for the normal scenario

Retailer	Product	Demand min	Demand max	Satisfied	Percentage
Retailer 20	Meal box	3900	3900	3900	100
Retailer 7	Meal box	3900	3900	3900	100
Retailer 8	Meal box	5200	5200	5200	100
Retailer 4	Meal box	6500	6500	6500	100
Retailer 14	Meal box	1300	1300	1300	100
Retailer 5	Meal box	1300	1300	1300	100
Retailer 18	Meal box	6500	6500	6500	100
Retailer 15	Meal box	2600	2600	2600	100
Retailer 3	Meal box	5200	5200	5200	100
Retailer 10	Meal box	2600	2600	2600	100
Retailer 2	Meal box	2600	2600	2600	100
Retailer 12	Meal box	5200	5200	5200	100
Retailer 1	Meal box	1300	1300	1300	100
Retailer 13	Meal box	6500	6500	6500	100
Retailer 17	Meal box	5200	5200	5200	100
Retailer 19	Meal box	1300	1300	1300	100
Retailer 6	Meal box	2600	2600	2600	100
Retailer 9	Meal box	6500	6500	6500	100
Retailer 11	Meal box	3900	3900	3900	100
Retailer 16	Meal box	3900	3900	3900	100

Table 3. Supply chain costs for the normal scenario

SC costs	Value (AUD)

Total production cost	624,000.00
Total transportation cost	3,222,986.22
Total other cost	91,250.00

Table 4. Production related outputs in manufacturing facilities for disrupted scenario

Manufacturing facility	**End product**	**Amount**	**Production cost (AUD)**
Manufacturer _ NT	Meal box	19825	158600
Manufacturer _ WA	Meal box	24505	196040
Manufacturer _ QLD	Meal box	2000	16000
Manufacturer _ NSW	Meal box	19125	153000
Manufacturer _ VIC	Meal box	32565	260520

Table 5. Demand fulfillment related outputs from retailers for disrupted scenario

Retailer	**Product**	**Demand min**	**Demand max**	**Satisfied**	**Percentage**
Retailer 9	Meal box	8125	8125	8125	100
Retailer 12	Meal box	6760	6760	6760	100
Retailer 6	Meal box	3380	3380	3380	100
Retailer 10	Meal box	3380	3380	3380	100
Retailer 13	Meal box	8125	8125	8125	100
Retailer 5	Meal box	1560	1560	1560	100
Retailer 15	Meal box	3380	3380	3380	100
Retailer 2	Meal box	3380	3380	3380	100
Retailer 4	Meal box	8125	8125	8125	100
Retailer 19	Meal box	1560	1560	1560	100
Retailer 3	Meal box	6760	6760	6760	100
Retailer 7	Meal box	4680	4680	4680	100
Retailer 18	Meal box	8125	8125	8125	100
Retailer 8	Meal box	6760	6760	6760	100
Retailer 1	Meal box	1560	1560	1560	100
Retailer 11	Meal box	4680	4680	4680	100
Retailer 20	Meal box	4680	4680	4680	100
Retailer 14	Meal box	1560	1560	1560	100
Retailer 16	Meal box	4680	4680	4680	100
Retailer 17	Meal box	6760	6760	6760	100

SC costs	**Value (AUD)**
Total production cost	784,160.00

Table 6. Supply chain costs for the disrupted scenario

Total transportation cost	4,012,097.55
Total other cost	91,250.00

Disrupted scenario

In a scenario of disruption characterized by a 25% surge in demand, the leagile supply chains of food manufacturers efficiently cater to heightened customer needs. This is achieved by strategically utilizing postponement and just-in-time inventory strategies within their production systems. Amid such disruptions, where retailer demands experience sudden spikes, manufacturing facilities swiftly adapt. These facilities convert raw materials sourced from suppliers into final products, such as meal boxes, aligning precisely with the escalated demand. Given the perishable nature of the food product, inventory management is meticulous, aiming to keep stock levels minimal while accounting for safety buffers. The combined approach of postponement and just-in-time inventory management empowers these companies to fulfill customer demands quickly. This strategy involves delaying certain customization processes until the moment of customer order placement, enhancing responsiveness and curtailing lead times. By harmonizing production with real-time demand, manufacturing processes are optimized to align with immediate requisites, enhancing customer satisfaction at the cost of elevated total SC costs. For detailed production insights, including processed meal box quantities and production costs, see Table 4. Additionally, Table 5 details retailer demand fulfillment metrics, offering a comprehensive view of demand fulfillment levels. To grasp overall operational costs in the disrupted situation, refer to Table 6, which provides a breakdown of expenses across the entire SC.

Therefore, the leagile supply chain model embraced by food manufacturers excels in addressing disruptions marked by demand surges. The strategic application of postponement and just-in-time inventory techniques enables these firms to respond effectively to customer needs while refining production procedures and maintaining prudent inventory levels.

5. Conclusions and future research directions

The leagile supply chain emerges as a vital strategy in the dynamic food manufacturing landscape, seamlessly blending lean and agile strategies. This helps businesses to navigate normal and disrupted scenarios adeptly. Leagile SCs employ postponement and just-in-time inventory strategies in the normal scenario, harmonizing production and demand for efficient inventory management, reduced lead times, and timely customer satisfaction. The alignment of production processes with orders optimizes resource utilization, embodying lean principles. The true strength of leagile SCs shines during disruptions, responding swiftly to a surge in demand. By delaying customization until orders are received, companies enhance responsiveness, mitigating risks of stockouts or overstocking. This adaptability aligns with agile methodology, fulfilling customer needs without compromising efficiency. Looking forward, future research could refine leagile strategies. Advanced data analytics and predictive modeling could enhance demand forecasting, enabling proactive decisions. Exploring IoT and blockchain may enhance transparency and traceability, improving quality control and risk management. Integrating sustainability into leagile SCs balances lean and agile principles with environmental concerns, leading to optimized resource use and reduced waste. Therefore, the leagile SC model blends efficiency with adaptability, enabling food manufacturers to tackle routine and unexpected challenges. As the industry progresses, refining leagile strategies and embracing technology and sustainability will reshape food manufacturing SCs, elevating standards and customer experiences.

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Biographies

Towfique Rahman is pursuing a PhD majoring in supply chain management and working as a casual/sessional academic at UTS Business School, University of Technology Sydney (UTS) and Macquarie Business School, Macquarie University, Sydney, Australia. Additionally, he has worked as a research assistant on diverse projects at UTS and Griffith University. He has a bachelor's degree from the Islamic University of Technology (IUT-OIC) and a master's degree from Bangladesh University of Engineering and Technology (BUET). Previously, he worked as a supply chain executive for well-known companies such as MJL Bangladesh Limited, a strategic alliance partner of ExxonMobil. Rahman has an impressive publication record, with numerous articles published in esteemed international journals, including the International Journal of Production Research, Journal of Cleaner Production, Computers & Industrial Engineering, Energy, Production Planning & Control, Annals of Operations Research, and many more. He works as a reviewer for renowned international journals, such as the Journal of Cleaner Production and the International Journal of Production Research. Rahman's scholarly contributions have been well-received and have garnered significant citations. His research interests focus on resilient and sustainable supply chain management, supply chain risk management, energy-efficient supply chain, logistics, industry 4.0, circular economy, simulation, and supply chain network optimization.

Sanjoy Kumar Paul is an Associate Professor of Operations and Supply Chain Management at the UTS Business School, University of Technology Sydney, Sydney, Australia. Sanjoy's research interests include supply chain risk management, resilience and sustainability, applied operations research, modeling and simulation, and intelligent decision-making. Sanjoy has published more than 120 articles in top-tier journals and conferences, including the European Journal of Operational Research, Transportation Research Part E: Logistics and Transportation Review, International Journal of Production Economics, Journal of Business Research, International Journal of Production Research, Computers and Operations Research, Computers & Industrial Engineering, International Journal of Logistics Management, Business Strategy and the Environment, Journal of Cleaner Production, and Annals of Operations Research, among many others. He is also an associate editor, area editor, editorial board member, and active reviewer of several reputed journals. Sanjoy has successfully secured external grants from the Department of Defence, Department of Industry, Science, Energy and Resources, Department of Foreign Affairs and Trade, and Meat and Livestock Australia Limited. Sanjoy has received several awards in his career, including ASOR Rising Star Award from the Australian Society for Operations Research, Excellence in Early Career Research Award from UTS Business School, the Stephen Fester prize for most outstanding thesis from UNSW, and high impact publications awards for publishing articles in top-tier journals. He has been included in the top 2% of scientists in author databases of standardized citation indicators for the last three years (2020-2022).