Overview of Supply Chain Risk and Disruption Management Tools, Techniques, and Approaches

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1 Introduction

The influence of supply chain (SC) risk and disruption management on business performance and operations has been widely studied and discussed by scholars and practitioners for the last two decades. In recent years, the focus of SC risk and disruption management studies has shifted from relying on historical data to understanding the probability of occurrence and magnitude for each event that can materially disrupt operations, including identifying the top SC disruptions such as poor supplier performance, forecasting errors, transportation failures, etc. (Paul et al. 2021a, b). These traditional methods do not manage disruptions caused by unforeseen events, as evidenced by the recent Coronavirus (COVID-19) pandemic that caused large-scale and long-lasting disruption; its effects highlight the need for resilient approaches to managing risk and disruption in SCs due to unforeseen events (Chowdhury et al. 2021).

Today's disruptions of SCs are referred to as 'unknown unknown risks', because they are unidentified. The timing and locations of this category of risks are unpredictable despite the fact that businesses are operating in a VUCA (volatile, uncertain, complex, and adaptable) environment. Unfortunately, it is not possible to eliminate

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all risks from unknown unknowns, large and small, in SCs (Modgil et al. 2021). During the recent COVID-19 outbreak, SC operations were adversely affected by an unknown unknown risk on a large scale (Paul et al. 2021a, b). Because of social distancing and lockdowns during the COVID-19 outbreak, manufacturing capacity has been dramatically reduced (Rahman et al. 2021a, b), the distribution and transportation networks have been disrupted severely (Mu et al. 2021), the supply of essential products has been notably disrupted (Gholami-Zanjani et al. 2021), social and environmental sustainability practices have been adversely affected (Nicola et al. 2020), employee's health and safety issues have increased (Rehman and Ali 2021), and the financial performances of SCs have been significantly reduced (Razavian et al. 2021).

The primary focus of SC management is on maximizing profits and returns on investment; hence, managers devote less time and resources to risk and disruption management since they think risk management's return on investment is ignored. The COVID-19 outbreak has proven them wrong. According to a study conducted by the Australasian Supply Chain Institute, only 45% of organizations have developed a business continuity and resilience plan, and only 6.12% of organizations are able to manage risks, rated as 'excellent' in this category (Majumdar et al. 2021). As a matter of fact, most organizations do not have a risk management plan and do not consider the resilience of their SCs. Most managers design their SCs so that cost-efficiency is maximized at the expense of resilience, sustainability, and other risk management practices (Modgil et al. 2021). In spite of the fact that a cost-effective SC may be seen as a lucrative option in the short term, it might not last if managers only focus on maximizing profits and saving money (Gurtu and Johny 2021). Considering the recent COVID-19 pandemic, SC risk and disruption were significant, unpredictable, and disastrous. Therefore, it is important to examine this category of unknown unknown risks as well as the disruptions this category of risks may cause. In order to effectively manage SC risk and disruption, we need greater insight into different dimensions of risks, their causes and sources, tools for assessing them, strategies for ensuring SC resiliency, methods for long-term recovery, management approaches for implementing risk and disruption management tools and techniques, and strategies for overcoming barriers to implementation. Future megatrends require SC business models to change in order to manage risks and disruptions of this category in innovative ways.

This chapter explores SC risks, disruptions, and their effects. This chapter also explores the sources of SC risks, vulnerabilities, and uncertainties. Given that the COVID-19 pandemic has disrupted global SCs and raised numerous problems, this chapter also investigates large-scale SC disruptions and their long-term consequences. The chapter further discusses resilience strategies to manage SC risks and disruption as part of an SC risk management approach. In this section, SC sustainability, adaptability, and viability are also briefly discussed. Finally, tools, techniques, and approaches applied in SC risk management are described in this chapter, so academics and professionals can better understand how to manage SC risks. Conclusions are drawn that highlight future research directions for the study of SC risk management.

2 Supply Chain Risks and Disruptions

Supply chain risks are divided into two categories: "micro risks" and "macro risks" (Gupta and Ivanov 2020). Micro risks in SCs arise primarily as a consequence of daily operational issues such as unexpected supplier failures, equipment failures, manufacturing shut-downs, port congestion, lead time changes, and late delivery owing to transportation limitations (Shekarian and Mellat Parast 2021). Macro risks, on the other hand, are often brought about by large-scale disruptions like natural disasters, disease outbreaks, and pandemics (Can Saglam et al. 2020). Unpredictable accidents in SC networks can destabilize the balance and profitability of SCs; they must be handled to re-establish balance and manage possible risks and disruptions. Unpredictable events might include unexpectedly large orders, demand spikes, supplier supply delays owing to operational risks, production unit malfunctions, and so on (Blackhurst et al. 2018). Risks arise as a result of SC insecurity. Micro and macro interruptions in SC networks may wreak havoc on operations. Natural disasters, geopolitical unrest, terrorist attacks, epidemics, and pandemics all add to the SC's insecurity. Uncertainty creates risks, resulting in the disruption of SCs. Deviations from the planned structure of SC networks are caused by a variety of circumstances. Purposeful and non-purposeful deviations can both impact SC choices, causing SC uncertainty (Macdonald et al. 2018). Theft, terrorism, and financial diversion are examples of purposeful deviations. A non-purposeful divergence may be caused by environmental, economic, or technical factors (Scala and Lindsay 2021). Natural disasters, diseases, and pandemics, such as the recent COVID-19 pandemic, are all examples of unintentional environmental deviations. Non-purposeful economic deviations can have a variety of repercussions, including bull-whip effects and supply-demand variations.

Numerous causes of uncertainty in SCs have been found by researchers, resulting in risks, disturbances, and disruptions. An overview of the causes of SC risk is shown in Fig. 1, taken from the literature (adapted from Ivanov and Sokolov (2010)).

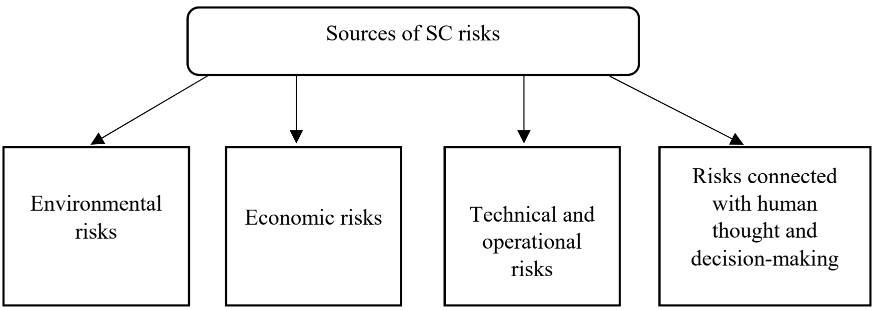

Fig. 1 Sources of risks in SCs. Adapted from Ivanov and Sokolov (2010)

The sources of different SC risks are classified into three groups: (i) internal organizational risks, (ii) SC internal risks, and (iii) external risks (Prakash et al. 2017). The sources of risks in SCs highlighted in Fig. 1 include both internal and external risks.

Environmental risks refer to external, uncontrollable changes. It is difficult to assess and comprehend the extent to which these changes create instability in the usual corporate environment (Christopher et al. 2011). A business SC network needs to understand how a changing environment affects the network, what tactics it can employ to manage the change, and how to maintain a balanced network during the change. Environmental risks include natural disasters, behavioral uncertainties, and goal uncertainty (Majumdar et al. 2021). Uncertainty about the dependability of suppliers, changes in customer preferences and behavior, the unpredictable activities of rivals, changes in product quality, volatility in inter-firm interactions, and other factors can all contribute to SC environmental risks (Kamalahmadi and Parast 2017). Changes in product supply and demand, changes in customer choices and preferences, and changes in technology characterize dynamic environments. The SC network should never overlook the consequences of environmental changes. The demand of consumers, supply from suppliers, technological infrastructure, and rivals within SC networks all have a significant impact on environmental uncertainties. As a result of these environmental uncertainties, demand, supply, manufacturing processes, and SC network control are all unpredictable (Diabat et al. 2013).

Economic uncertainty is a major source of risk throughout SC networks. Economic concerns in SCs include increases in inflation, global recessions, and domestic losses (Cavalcante et al. 2019). The trade conflict between the United States and China, Brexit, worldwide lockdowns, and the COVID-19 pandemic have all had a negative impact on global SCs (Pournader et al. 2020). Businesses cannot control every event outside their doors. In response to external changes, businesses should operate with SCs that are flexible, dynamic, and strategic.

Businesses face various technical and operational uncertainties in their SCs. Examples of technical and operational uncertainties include production failures due to technical insufficiency and problems, lack of experience, etc. (Pavlov et al. 2019). Some operational and technical uncertainty may result in a shortage of capacity, resulting in manufacturers being unable to meet surges in consumer demand. Lacking capacity increases SC's costs. Manufacturers must invest more in high-tech capabilities to respond rapidly to technical and operational uncertainty (Shekarian and Mellat Parast 2021).

Uncertainty in human thought and decision-making can also contribute to SC risks. Such uncertainty is evidenced by inadequate coordination, poor control of logistics, poor decision-making ability, insufficient top-management knowledge, and late top-management decisions (Ivanov and Dolgui 2021b). Human knowledge is extremely valuable in this age of artificial intelligence. Artificial intelligence may produce problems in SC networks that are not guided by human intelligence (Modgil et al. 2021). Managing SC uncertainty necessitates the use of human intelligence and improved decision-making abilities.

Uncertainty causes SC risks, variations, and interruptions. All of these risks cause major disruptions at the macro and micro levels of SCs (supply, demand, manufacturing, transportation, and financial levels). Practitioners must understand the sources of SC risks and uncertainty in order to prevent interruptions. The next section examines the uncertainties, risks, and interruptions that may result from large-scale SC disturbances.

3 Large-Scale Supply Chain Risks and Disruptions

Large-scale risks and disruptions, such as the COVID-19 pandemic, have had a considerable influence on global SC networks, although the degree of their impact is yet unknown. Nonetheless, getting a detailed understanding of the repercussions of SC disruption is critical for developing risk management methods to mitigate the effects. The COVID-19 pandemic is an example of SC disruption on a large scale (Moosavi and Hosseini 2021).

During the global pandemic, SCs worldwide saw significant changes in demand for both high- and low-demand items (Paul and Chowdhury 2020b). As a result, suppliers struggled to ship raw materials to manufacturers in other countries, preventing businesses from ramping up production capacity to match increases in consumer demand. Due to consumers' hoarding behavior and sudden panic-purchasing of high-demand items, supermarkets were badly depleted of necessary supplies (Hall et al. 2020).

Several governments throughout the world established stringent border restrictions, imposed lockdowns, and shut down activities within their borders in an effort to flatten the COVID-19 infection curve (Wang and Yao 2021). Manufacturers struggled to get raw materials from suppliers in restricted (quarantined) zones. Manufacturers typically have only one supplier from a single location. Manufacturing facilities were impacted by supply interruptions and were unable to boost production in order to fulfill consumer demand (Belhadi et al. 2021). As a result, supply interruptions had a significant influence on the whole SC network.

Because the government of most of the countries enforced a restrictive social distancing regulation, most manufacturers were unable to improve their infrastructure to allow their staff to continue working. Due to supply and demand problems, businesses were unable to increase manufacturing capacity. With huge losses and debt, several industries were forced to shut down their manufacturing operations (Choi 2020).

Timely delivery of purchased items to consumers is critical for company SCs to relieve a backlog of orders and related expenditures (Valipour Parkouhi and Safaei Ghadikolaei 2017). Another strategy for firms to preserve goodwill is to deliver items to customers on schedule. Businesses associated with high-demand luxury products had difficulty maintaining quick deliveries due to a shortage of products caused by a manufacturer's low production capacity and lockdowns caused by COVID-19 infections (Rahman et al. 2021a, b).

There was an upsurge in demand for vital supplies as a result of the COVID-19 pandemic inducing fear of lockdowns. Global SCs of critical items failed to foresee the exact need of consumers due to a lack of dynamic demand forecasting skills, technology, and infrastructure. Decision-makers were unable to make timely decisions to restore SC networks due to a lack of knowledge about the exceptional disruption created by the crisis (Hobbs 2020).

Throughout the pandemic, COVID-19 severely disrupted the global SCs of manufacturers. In order to meet consumers' needs, manufacturers were unable to ramp up production. In response, manufacturers of essential products faced increased costs due to shortages. The decline in demand for luxury products led many companies to limit production, reducing profits. Major disruptions in global SCs seriously impacted their financial management (Razavian et al. 2021).

As a result of the COVID-19 pandemic, global SCs have suffered serious degradation in sustainability performance (Rahman et al. 2021a, b). Due to high consumer demand, manufacturers of personal protective equipment had to expand production capacity, such as facemasks, hand-sanitizer, etc. (Rahman et al. 2021a, b). Global SCs suffered significant shortage costs during the closures and shutdowns. As a result of the pandemic-induced global economic recession, many manufacturers had to shut their doors permanently which led to many employees losing their jobs. Companies' reputations were also severely damaged (Karmaker et al. 2021).

4 Managing Supply Chain Risks and Disruptions

Supply chain risk and disruption management is the process of identifying and managing SC risks through a coordinated strategy among SC stakeholders in order to decrease overall SC network vulnerability and disruption (Kilubi 2016). Many scholars have proposed that SC participants employ risk and disruption management process methods to cope with risks and uncertainties posed by or affecting logistics-related activities or resources (Manuj et al. 2014). To maintain profitability and continuity, SC risks are managed by coordination or collaboration among SC participants. Some studies have focused on identifying and managing hazards within the SC network and outside through a coordinated strategy among SC stakeholders to mitigate overall SC vulnerability (Lintukangas et al. 2016). Furthermore, the SC risk management method is distinguished by a cross-company focus on identifying and reducing risks, not only at the business level but also across the whole SC (Wildgoose 2016). In a nutshell, SC risk and disruption management can be defined as "an interorganizational collaborative effort that uses quantitative and qualitative risk management approaches to discover, assess, mitigate, and monitor unanticipated macro and micro level occurrences or situations that might have a negative impact on any portion of a supply chain" (Ho et al. 2015). To manage risk and disruption in SCs, many resilient and sustainable strategies are discussed in the literature. Many dynamic adaptation strategies have recently been suggested to make SCs sustainable and viable in the case of macro-level disruptions, such as the pandemic caused by COVID-19.

5 Resilience Strategies for Managing Supply Chain Risks and Disruptions

The goal of resilience strategies is to make SCs more resilient to disturbance. An efficient SC keeps costs down. A resilient SC, on the other hand, may not be cost-effective at first but it will save firms from interruptions in the long term (Dubey et al. 2019). Researchers are discussing a robust and resilient-sustainable SC. Reconfigurable techniques can aid in the resilience of a healthy and viable SC (DuHadway et al. 2019). During large-scale disruptions, many tiers of SCs may experience simultaneous disturbances, such as supply disruptions, demand disruptions, and logistical disruptions. For example, the COVID-19 pandemic impacted all levels of the SC (Dohale et al. 2021). Due to supply and demand disruptions, producers of essential items such as personal protective equipment (especially facemasks), food, and so on expanded production to fulfill customer demand (Rahman et al. 2021a, b). As a result, there was a significant increase in the waste of critical items such as facemasks in many nations throughout the world. In order to make SCs more viable, resilience strategies must be implemented to maintain social, environmental, and economic performances (Scala and Lindsay 2021). Table 1 describes numerous techniques for increasing the resilience of SCs at supply-level, demand-level, production-level, inventory-level, delivery and transport-level, and financial-level.

6 Supply Chain Sustainability, Adaptability, and Viability

Several scholars have concentrated on resilience methods, sustainability strategies, and so on as means of mitigating the effects of large-scale SC disruptions. Academicians and practitioners have been paying attention to recovery planning for large-scale disruptions (Razavian et al. 2021). The majority of researchers have also focused on response and preparedness strategies (Rahman et al. 2021a, b). Furthermore, most resilience strategies have focused on managing short-term and long-term disruptions. Few strategies were designed to reconfigure SCs from a sustainability point of view (Shishodia et al. 2021). Reconfigurable strategies are those that can readily rearrange SCs in order to survive in a disturbed condition. Despite its importance, sustainable reconfigurable strategies have been little discussed in the literature. The COVID-19 pandemic has demonstrated that global SCs must be redesigned in order to sustain any future extraordinary disruptions so that sustainability and resilience are both maintained (Herold et al. 2021). Decision-makers must employ reconfigurable

Table 1 Selected resilience strategies to manage SC risks and disruptions

SC risks	Resilience strategies	Risk management application to make current SC more resilient	References
Demand risks	Capacity expansion	When there is a rise in demand for vital commodities, an increase in manufacturing capacity may assist in fulfilling that need	Rahman et al. (2021a, b), Ivanov (2020), Ivanov (2019), Ivanov (2021a), Ivanov (2021b), Luthra et al. (2011)
	Purchasing in an emergency	Increasing emergency sourcing will assist in expanding output in order to meet the rise in demand	
	Create new production capacity	Alternative items can be created as a result of the repurposing of manufacturing to suit the temporal need. To fulfill increased healthcare demand during the COVID-19 epidemic, automotive companies, for example, provide valves for respirators	
	Collaborating horizontally and vertically	Horizontal and vertical collaboration can readily promote resource sharing to fulfill consumer needs, particularly during pandemics such as COVID-19	
Supply risks	Alternative sourcing	Alternative sourcing helps maintain the supply in the event of a main supplier breakdown	Dolgui et al. (2018), Dolgui and Ivanov (2021), Ivanov (2021b), Ivanov (2021a), Chowdhury et al. (2021)
	Diverse sourcing	The presence of a diverse set of suppliers improves supply flexibility	
	A local source of supply	Local sourcing allows businesses to be more flexible while also saving money on transportation, which might lead to strong redundancy in the case of a worldwide major disruption such as the COVID-19 pandemic	
	Grouping suppliers by type	When suppliers are categorized by type, it is easier to identify key providers and build emergency preparations	

(continued)

Table 1 (continued)

SC risks	Resilience strategies	Risk management application to make current SC more resilient	References
	Inventory at risk/ Strategic stock	Strategic stock/risk inventory may be beneficial in fulfilling changing customer needs and avoiding stock-outs	
Production risks	Back shoring/ reshoring	We can minimize susceptibility and boost robustness by reshoring and back shoring, which is critical in cases such as the COVID-19 pandemic	Dolgui and Ivanov (2020), Chowdhury et al. (2021), Ivanov (2021b), Paul and Chowdhury (2020a, b), Tarafdar and Qrunfleh (2017), Pavlov et al. (2019), Manuj et al. (2014)
	Local production and nearshoring	Nearshoring and domestic manufacturing help to minimize production vulnerability and boost resilience in the event of a disruption	
	Capacity repurposing	By altering the production system and supply base, repurposing can help to launch rapid demand-supply reallocation	
	Diversifying and substituting products	It may be beneficial to develop a big quantity of alternate items in the event of an SC interruption	
	The postponement of products	Manufacturers can respond swiftly to fluctuating client demand and increase inventory efficiency by deferring production	
	Developing decentralized manufacturing systems	When a major disruption occurs, such as the COVID-19 pandemic, dispersed manufacturing facilities improve resilience	
	Flexible and modular product lines	This aids in responding to varying customer demands during interruptions	
	Facility for subcontracting	Subcontracting permits production to continue in the case of an interruption at the principal manufacturing plant	
	Make use of idle capacity	Allows emergency items to be manufactured	

(continued)

Table 1 (continued)

SC risks	Resilience strategies	Risk management application to make current SC more resilient	References
	3D printing	Produces a variety of products and services in order to keep supply and demand in check	
	The industrial revolution 4.0	Robotic-enabled smart manufacturing facilities can use digital twins to regulate production and scheduling based on real-time data	
	Robotics and human collaboration	In the face of extreme disruptions, such as the COVID-19 pandemic, the use of robotics in production may boost capacity	
Transportation and delivery risks	Collaborate with other transporters	Collaboration with other transportation providers helps to improve the robustness of product delivery to retailers and consumers when a major disruption occurs	Gunasekaran et al. (2015), Paul et al. (2017), Ivanov (2021a), Aldrighetti et al. (2021), Chowdhury et al. (2021), Ishfaq et al. (2021)
	Increase the number of distribution centers	Distributing closer to consumer zones strengthens logistics and enables seamless delivery during disasters	
	Multiple-mode and multi-route shipments	Multimodal and multi-route shipments enable transportation arrangements to be changed with an alternate route or method of transport amid delays, ensuring seamless delivery	
	Availability of backups	When the primary warehouse is down, backup facilities take over and continue the distribution process	
	Developing an emergency distribution plan	To organize an emergency delivery, the emergency supply chain (e.g., healthcare, food supply chain) can collaborate with the commercial supply chain	

(continued)

Table 1 (continued)

SC risks	Resilience strategies	Risk management application to make current SC more resilient	References
	The Omnichannel	By changing distribution pathways, the omnichannel helps to maintain material flow	
Information management risks	Blockchain technology and advanced tracking	Increases supply chain visibility, identifies problems, and aids in recovery	Durach et al. (2021), Rahman et al. (2021a, b), Ivanov (2017), Ishfaq et al. (2021)
	Implementing enterprise resource planning (ERP)	Bringing internal and external SCs together improves visibility	
	Using big data for analytics	Big data analysis in supply chains may be used for continuous monitoring, risk assessment, and opportunity mapping	
	Creating a digital twin	A cyber-physical system allows for the creation of a virtual model of a physical supply chain, forecasting, and design change	
Financial management risks	An innovative public-private partnership	During supply chain interruptions, government assistance can help alleviate financial risks	Papadopoulos et al. (2017), Ivanov and Sokolov (2019), Dong et al. (2018)
	Liquidity reserves	By maintaining a liquidity reserve, the company is able to sustain supply chain activities even in extremely disruptive situations such as the COVID-19 pandemic	
	Business insurance	If transportation is hindered or items are destroyed, insurance might act as a backup plan for the financial management of SCs	

SC methods to make SCs more robust and sustainable. Researchers have suggested that greening SCs will lead to greater sustainability, while others suggest improving the economic, social, and environmental performance of SCs (Paul et al. 2021a, b).

In times of extreme disruption, meeting customers' increased demand (due to panic-buying) helps improve the SC's social performance (Ghosh and Shah 2015). Increased manufacturing capacity ensures that customers' needs are met (Rahman et al. 2021a, b). Addressing health and safety concerns throughout SCs during massive disruptions such as the COVID-19 pandemic assists in boosting the SC's social performance (Ivanov 2021c). Increasing the capacity to manufacture biodegradable or organic products helps to improve the SC's environmental performance (Vilarinho et al. 2018). The circular economy, effective logistics, and the development of waste management capability may all help to improve SC's environmental performance (Pivnenko et al. 2016). SC's environmental challenges are sustained by green production capabilities (Hsu et al. 2013). Controlling carbon emissions improves environmental sustainability across the SC, particularly in the transportation sector (Aldrighetti et al. 2021). Checking shortage costs by swiftly satisfying consumers' demand and orders improves the SC's economic performance. Profit maximization is achieved by lowering overall SC expenses, and business diversity aids in improving the SC's economic performance (Shahed et al. 2021). Increased sharing of resources through vertical and horizontal collaboration aids in the preservation of economic performance during major interruptions, such as the COVID-19 pandemic (Mehrotra et al. 2020). Even in the face of large disruptions such as the COVID-19 pandemic, pooling financial resources among SCs and other horizontal organizations aids in the preservation of economic performance (Pettit et al. 2019). Super disruptions, such as the COVID-19 pandemic, cause SCs to be disrupted, resulting in the partial or complete closure of manufacturing facilities for a period of time. Taking urgent steps to restore SC activity by implementing recovery strategies can assist SC networks and businesses to survive economic interruptions.

Adaptation strategies, such as intertwining, substitution, scalability, and repurposing segmented by Ivanov (2020), can be used to reshape SCs when there has been disruption on a large scale in order to restore SCs to a new normal state. The following presents a brief description of the adaptation strategies:

Intertwining adaptation strategy: The COVID-19 pandemic caused severe disruptions in demand for many essential and luxury products. For example, low demand from consumers initially led to a severe shortage of semiconductors in the automotive and electronic industries. In order to accelerate their production, semiconductor companies needed to collaborate with each other; this is known as intertwining SCs (Ivanov 2021c). Manufacturers need to adapt dynamic intertwining strategies to survive disruption and ensure SCs remain viable (Salama and McGarvey 2021).

Substitution adaptation strategy: Strategies for substitution adaptation are implemented at the level of a viable SC's network and resource capabilities. Reconfiguration of network structures and product substitution are among the main adaptation strategies in this category (Ivanov 2021c). The emerging global pandemic caused by COVID-19 forced most countries of the world to close their borders to countries more susceptible to the disease (Michel-Villarreal et al. 2021). In one country, manufacturers who depended on both local and overseas suppliers were faced with severe supply shortages. For the smooth delivery of raw materials, most researchers suggested looking for alternative/backup suppliers (Paul et al. 2021a, b).

Scalability adaptation strategy: Similar to the substitution adaptation strategy, the scalability adaptation strategy works at the network and resource capabilities level of a viable SC (Ivanov 2021c). The demand for essential items, such as food, facemasks, ventilators, etc., soared during the pandemic. For essential manufacturers to fulfill the excess demand of the customers, they need to expand their production capacity and SC networks (Mohammed et al. 2021).

Repurposing adaptation strategy: The adaptive repurposing strategy also contributes to the network and resource capacity of a viable SC as well as substitution and scalability (Ivanov 2021a). In response to the pandemic, Ford Motor Company strategically used its production line to produce personal protective equipment, such as face shields (Belhadi et al. 2021). Many garment factories were unable to sell enough apparel items during the pandemic so they turned their production lines to facemask production instead (Paul et al. 2021a, b).

7 Tools, Techniques and Approaches Applied in Supply Chain Risk Management

There are three types of methodology for SC risk management approaches found in the literature: (*i*) quantitative, (*ii*) qualitative, and (*iii*) empirical methods (Chowdhury et al. 2021). Some are individual methods, while others are integrated methods. Figure 2 shows the types of SC risk management methods.

7.1 Quantitative Methods

Researchers used a range of quantitative modeling approaches to justify strategies for making SC networks more stable, viable, and sustainable. From the literature,

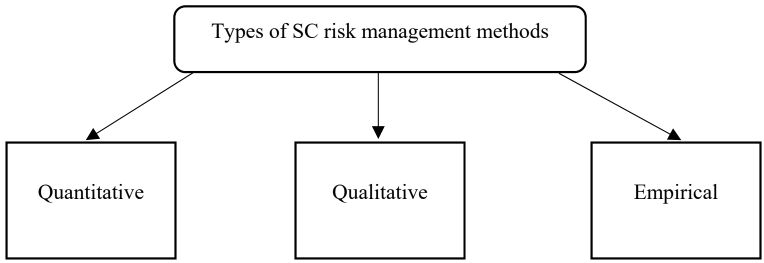

Fig. 2 Types of SC risk management methods (Rahman et al. 2022)

Ivanov and Dolgui (2021a, b) categorized modeling approaches to aid in network-wide assessing, decision-making, and process management, thus justifying steps to make SCs more resilient and sustainable.

Bayesian networks, reliability theory, complexity theory, petri nets, Markov chains, and other tools may be used to perform network-wide analyzes to identify bottlenecks in SC networks. Hosseini et al. (2019) used Bayesian networks and proposed resilience strategies for supplier selection during times of disruption. Siva Kumar and Anbanandam (2020) proposed a method based on complexity theory in order to see how the SC resilience can improve building capabilities and resilience. Gao (2015) investigated versatile risk mitigation in SCs by presenting a Markov model of demand volatility and incorporating it into dynamic mathematical programming for hedging of inventory. It is highly crucial to detect the bottlenecks in SCs that might enhance SC hazards through a network-wide investigation.

Mathematical optimization is an excellent modeling technique for making decisions. Soren and Shastri (2019) employed a multi-objective optimization approach to lower overall SC costs by managing production gaps. The model required considering disruption during procurement and production. A mathematical model developed by Lücker et al. (2019) was used to assist in analyzing decisions for appropriate inventory and redundancies under stochastic demand. Hosseini et al. (2019) evaluated resilient supplier selection approaches for recovering from supply-side disruptions using a mixed stochastic bi-objective mixed-integer programming model and a probabilistic graphical model. Tucker et al. (2020) investigated ways to reduce product (drug) shortages, and Fattahi et al. (2017) evaluated demand volatility and long lead time. Both authors examined the defined problems using multi-stage stochastic programming.

In contrast, several simulation methodologies are used for process control analysis (Ivanov and Dolgui 2021a). Using a system dynamics simulation, Chen et al. (2020) investigated the resilience initiatives for oil imports in the face of shock. A model based on agent-based simulation was developed by Rahman et al. (2021a, b) to anticipate and mitigate the impacts of the COVID-19 pandemic. However, Tan et al. (2020) examined SC resilience techniques in an SC network using a discrete event model and agent-based modeling (ABM). In exploring process control analysis, ABM is a superior method to understand stakeholder behavior in SCs. Mixed approaches of mathematical optimization and simulation methods may greatly assist in developing models for viable SC networks and evaluating process decision-making strategies for a better understanding of the consequences of large-scale SC disruptions.

7.2 Qualitative Methods

Several qualitative methods are described in the literature, either as individual methods or integrated with other qualitative or quantitative methods. Among the important qualitative methods are the case study, interview, and survey methods. For instance, Herold et al. (2021) conducted interviews with logistics service providers to learn how they dealt with the COVID-19 epidemic. Modgil et al. (2021) conducted expert interviews to investigate the prospects for improving SC resilience through distribution, visibility, and sourcing using AI. Also, Werner et al. (2021) investigated non-financial variables of organizational effectiveness in a case study. Papadopoulos et al. (2017) collected data and surveyed social media to evaluate resilience in SC networks for sustainability. In order to grasp knowledge regarding SC risk management, qualitative methods, such as case studies, surveys, and interviews, are extremely useful.

7.3 Empirical Methods

The empirical method refers to a procedure for conducting an investigation based primarily on experimentation and systematic observation rather than theoretical speculation. An empirical approach can provide valuable insight into the behavioral side of SC risk management. Empirical methods include some tools such as structural equation modeling (SEM), partial least squares-SEM (PLS-SEM), exploratory factor analysis, hierarchical regression analysis, and others. SEM was used, for example, by Vanpoucke and Ellis (2019) to examine supply-side risk management strategies. To analyze logistics resilience strategies, Liu and Lee (2018) used PLS-SEM. Using covariance-based SEM (CB-SEM), Singh and Singh (2019) examined how data analytics can help firms to make their SCs more resilient. Asamoah et al. (2020) utilized a method called exploratory factor analysis (CFA) to investigate the association between social network ties, SC resilience, and customer-oriented performance. The use of empirical methods in SC research requires primary evidence-based data where the output is reliable and applicable to the management of SC risks.

8 Technological Approaches Applied in Supply Chain Risk Management

The literature suggests several technologies for managing SC risks and disruptions. A few of the many technological approaches include blockchain analysis, big data analytics, digital twins, 3-D printing, industrial revolution 4.0, robotics, artificial intelligence, machine learning or reinforcement learning, and the Internet of Things (IoT). Supply chains can be greatly improved by blockchain technology which can offer faster and more cost-efficient delivery of products, improved traceability, improved coordination between partners, and improved access to financing. By tracing the origins of raw materials to the end consumers, including the production stages, blockchain technology can significantly assist in minimizing SC risks. Big data analytics provide the decision-makers for the SCs of companies with information and quantitative approaches that help them make more intelligent decisions.

The system consists of two new features in particular. To begin with, it expands the dataset for analysis beyond the conventional internal data held in enterprise resource planning (ERP) and SC management systems. In addition, it analyzes both new and old data sources using powerful statistical approaches. Using this method, SC decision-makers can make better decisions about everything from front-line operations to choosing the right SC operating model. A virtual SC replica with hundreds of assets, warehouses, logistics, and inventory placements is known as a digital twin. The digital twin simulates the SC's performance using advanced analytics and artificial intelligence, including all the complexity that leads to value loss and risk. In the SC, 3D printing allows for a great deal of versatility in terms of what may be printed. They print with a variety of materials, such as polymers, to print hard objects such as eyewear. By combining a rubber/plastic powder, users can create flexible items such as phone cases. During extreme disruptions like the COVID-19 pandemic, 3-D printing technology can help to add value to traditional SCs. During the pandemic, 3-D printing technology greatly aided in the production of healthcare products, such as personal protective equipment (PPE) and facemasks, to fulfill increased customer demand. Industry 4.0 necessitates a paradigm shift in how products and services are manufactured, distributed/supplied, sold, and consumed in the SC, resulting in major structural theoretical evolution and revolution in operations and SC management. Industry 4.0 is the future of SCs allowing them to deal with future disruption. Automated SC functions can be greatly streamlined by integrating robots with other automation systems. The use of IoT, artificial intelligence, machine learning, or reinforcement learning is an extremely powerful tool in capturing the big picture of SCs and solving their risk-related problems. Therefore, to manage SC risks, it is crucial for SC decision-makers to integrate the latest technologies into their SCs as much as possible.

9 Conclusions and Research Directions

A business decision-maker must act promptly in order to ensure SCs are viable in the long term, resilient, and sustainable. To ensure that SCs remain strong and sustainable, they should use reconfiguration methodologies to align SCs whenever disruptive events occur. It is imperative that SC managers develop methodologies that are reconfigurable, adaptive, robust, long-lasting, and dynamic in order to recover from super disruptions. In addition, it is crucial to understand the risks and vulnerabilities associated with SCs, their causes and factors, and how these risks and vulnerabilities can disrupt operations. This is an extremely important research avenue for SC risk management. When massive disruptions occur, such as the COVID-19 pandemic, different levels of SC networks are affected simultaneously. However, the long-term consequences remain unknown. Scaling, substitution, repurposing, and interweaving are just a few of the adaptation tactics that can be used to deal with the unknown unknowns of a pandemic. Detecting and quantifying SC network uncertainty is crucial. However, it is important to know what risks are associated with large-scale

SC disruption and how such disruption may impact operations in the long term. This is another extremely important research avenue for SC risk management.

The profitability of SC networks depends on a reconfigurable technique that reduces the uncertainty caused by large-scale outages. Simply put, companies (and governments) throughout the world should build resilience into every important SC on the globe; this is the only way to deal with large-scale unpredictability. The manufacturing SC has been underrepresented in recent SC advancements, but it should now be the focus, brought under more systematic and coordinated supervision. This is because supply-side interruptions are the most common. Many SCs were impacted by the COVID-19 pandemic, first on the supply side and then on the demand side. Rather than focusing just on compliance, procurement should begin segmenting their entire supplier pool based on capabilities, expectations, and other situations. As a result, a secure, immutable, and trustworthy channel for real-time information flow between SC stakeholders is required, which can be established using emerging technologies such as the Internet of Things (IoT), big data analytics, blockchain, reinforcement learning, and artificial intelligence. These technologies are capable of identifying the source of disturbances and providing remedies. Practitioners may use such technologies to provide reconfigurable solutions that, in many circumstances, improve SC network resilience and sustainability. They may put technologies to the test and make substantial adjustments to the strategy's dynamic to make SC networks more feasible and resilient. A better understanding of resilience and sustainability strategies, tools, techniques, modeling methods, technologies, and future business models is an important research direction for managing short- and long-term risks and disruptions to SCs.

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