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SUPPLY CHAIN RESILIENCE AND RISK MANAGEMENT STRATEGIES AND METHODS

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ABSTRACT

Supply Chain Resilience and Risk Management strategies and methods

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The changing global market due to Industry 4.0 and the recent pandemic effect has created a need for more responsiveness in an organization’s supply chain. Supply chain resilience offers the firm not only to avoid disruptions but also to withstand the losses due to a disruption. The objective of this research is to find out how resilience is defined so far in other literature and find out the strategies available to gain the resilience fit for an organization. First, in the literature review, the previous studies on resilience were studied to understand what supply chain resilience means. Then, the key results and findings are discussed and conclusions are presented. The research found some interesting strategies for gaining the resilience fit. The benefits and the stakeholders for each strategy are also pointed out. These strategies can be used according to the organization's business strategy. These strategies aligned with the business strategy can make a huge difference to withstand potential disruption and gaining a competitive advantage against the market competitors.

Keywords: Supply Chain Resilience, Risk Management, Risk Management Strategies, Supply Chain Management

FOREWORD

This thesis was prepared for the master's degree in Product Management at the University of Oulu. The research mainly took place between February and July of 2021. Writing my thesis was a new and amazing experience since it was my first time doing a literature-based thesis on such a fascinating and current topic. I'd want to express my gratitude to my thesis supervisors, Jukka and Osmo, who were always willing to assist me when I encountered problems. Regular meetings, suggestions, and interim comments ensured that the thesis is progressing in the correct direction to the conclusion. I'm also thankful to the authors whose literature I used for this research.

I am grateful to my family for their unwavering support during my academic years. Finally, I'd also like to thank my friends who were there with me in my graduation journey and supported me in every way. Without your help, completing the academic route would have been very difficult, if not impossible. I'll never forget the university and my times in Oulu.

Oulu, 17.07.2021

Antor Habib Chowdhury
Author

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LIST OF ABBREVIATIONS

ADV	Advance Data Visualization
BCP	Business Continuity Plan
BDA	Big Data Analysis
GA	Genetic Algorithm
GSP	Generalized Sequential Pattern
ISCRM	Integrated Supply Chain Risk Management
ISM	Intertwined Supply Network
KPI	Key Performance Indicator
MBP	Multiple Backpropagation
NN	Neural Network
RMI	Risk Mitigation Inventory
SC	Supply Chain
SCI	Supply Chain Integration
SCOR	Supply Chain Operation Reference
SCRAM	Supply Chain Resilience Assessment and Management
SCRES	Supply Chain Resilience
SOM	Self-Organizing Map
SVM	Support Vector Machine
VUCA	Volatility, Uncertainty, Complexity, and Ambiguity

1 INTRODUCTION

1.1 Research background

The more we are going towards modern technology, the more we need our products at right time at the right place. As technology growth is now exponential, we are moving towards the Industry 4.0 revolution. So, the supply chain is becoming more responsive and more complex. New variables are coming which can affect the whole value chain. To deal with such variables, industries need to be proactive and need a way to manage the changes. When technology progresses and the industry grows more globalized, supply chains are becoming more complex, and they are rapidly transforming into supply chain networks (Wu et al. 2017). Firms in supply chain networks face challenges not just from demand fluctuations and customized requirements, but also from the operational decisions of their supply chain network partners (Hua et al., 2011). All of these problems increase the vulnerability of supply chain networks, rendering them more vulnerable to threats and delays (Rajagopal et al., 2017). In reality, local supply chain instability can expand and amplify across the supply chain network, causing extreme network disruption and avalanche (Hou et al., 2014; Mensah et al., 2015).

Supply chain disturbances are caused by a combination of an unintentional and unforeseen causing incident that happens elsewhere in the upstream supply chain network, inbound distribution network, or sourcing environment, as well as a consequential scenario that poses a significant challenge to the firm's regular business operations (Bode and MacDonald 2017). Regardless of the specialized market in which supply chains exist or the fundamental value of the products and services they deliver, disruptions, whether natural or human-caused, are an inextricable part of the global framework in which all supply chains operate. Localized disasters can occur, such as the 2019 wildfires in Australia (Edwards 2020) or the 9.0 magnitude earthquake that struck Japan in March 2011, resulting in the Fukushima Daiichi Nuclear Power Plant explosion. The earthquake not only wreaked havoc in Japan, but the rolling blackouts have wreaked havoc on global supply chains, forcing the partial closing of a GM truck plant in Louisiana, for example, owing to a shortage of Japanese-made components (Lohr 2011).

Additionally, the COVID-19 pandemic is a once-in-a-lifetime event that highlights the need to advance supply chain (SC) sustainability studies and activities. The coronavirus epidemic has a greater impact on the global and local economies. The availability of supply in global SCs has been sharply decreased, and production has been misbalanced. COVID-19 dispersal, according to Araz et al. (2020), is ‘breaking multiple global SCs.' The number of COVID-19 cases has increased exponentially across the globe, culminating in border closures, quarantines, and complete shutdowns in several critical installations, economies, and operations in the SCs as of early March 2020. The World Health Organization (WHO) declared the worldwide pandemic on March 11, 2020. Many organizations' SCs were especially vulnerable to coronavirus outbreaks due to their lean and globalized systems (Ivanov 2020). The COVID-19 epidemic has had a huge impact on all aspects of the economy and culture, and it has also tested the resistance of SCs.

After the global pandemic, there will be very few scopes for margin of error to recover the affected supply chain. The pandemic affected every industry, and the industries need a lot of time to recover from it. This is the right time to work on the Supply Chain Resilience tools. A resilient supply chain may rebound from the negative effects of unforeseeable delays and respond to unforeseeable future events. Resilience in a supply chain refers to the capacity to brace for and perform important activities after a disturbance, as well as the ability to regenerate and transition post-disruption into a shape that is best adapted to the newly "normal." While other supply chain management strategies such as reliability, robustness, risk mitigation, leanness, and others are critical for business progress, supply chain resilience is special in that it also focuses on recovery after a disruptive event (Golan 2020).

1.2 Research scope and objectives

This thesis is done as a part of the Product Management Master’s program at the University of Oulu under the supervision of the Industrial Engineering Management (IEM) research unit. The objective of the thesis is to analyze available supply chain resilience and risk management strategies and methods and understand how they can be beneficial to the companies.

The objective of this research is to do a literature review on supply chain resilience and risk management and analyze especially what type of strategies and methods exist for improving resilience including, for example, the SCRAM framework. SCRAM is a supply chain resilience assessment tool for understanding the supply chain capabilities and vulnerabilities of a company. (Pettit et al. 2010)

The objectives of the thesis can be achieved by answering two research questions:

1. How are supply chain resilience and risk management defined in the literature?
2. What strategies and methods are available for improving supply chain resilience?

The research questions are answered based on the literature review conducted in this thesis.

1.3 Research process and the thesis structure

In research, initially, the problem is defined in a broad general way. After feasibility checking, a working formulation can be set up and make the general topic into a specific research problem which is a crucial step for the research. Once the problem is formulated, similar studies already done should be carefully studied meaning the literature review. After that a research design can be made, then relevant literature is collected, analyzed, interpreted, and reported.

The literature review includes an analysis of previous research. The Supply Chain Resilience keyword was used in the beginning, then recent articles were studied for the literature review. When the strategy part came, resilience strategy was used as the new keyword and articles related to the proactive and reactive strategies were studied. The literature review section consists of supply chain management, its objective and key performance indicators (KPIs), supply chain resilience, risk management regarding the resilience, strategy to deal with the events, and finally literature review synthesis.

After the literature review, the results and key findings are reflected with the previous studies in the discussion section, and the conclusions are presented in the conclusions section.

2 LITERATURE REVIEW

In this chapter, the research questions are addressed by analyzing the existing available scientific literature data. The literature review is modeled in a way where very basic concepts about supply chain resilience and risk management are understood to define the capabilities and vulnerabilities. Further, the review is carried out to investigate the supply chain processes and the related performance measures.

2.1 Supply Chain Management

Supply chain management is the chain of activities starting from the raw material and ending with delivery to the customers. Sometimes it's even beyond that as after-sale service also needs some supply management as well. The main objective is to reduce the waste and make the chain smoother so that the right product can be delivered to the right place at right time. (Chopra 2000)

In a supply chain, every product starts with a strategy set by the organization with which the organization will do business. Every plan that will be made in the future must support the strategy from which there comes the Supply Chain strategy. Supply chain strategy is more specified within supply chain activities only, every action regarding supply chain will follow this strategy to make sure the organizational strategy to be fulfilled. For reaching that goal SC needs plans which consist mainly of the activities and the participants who are responsible for the activities to be done. For the activities, teams are formed based on the functions like Supplier management, Inventory management, demand management, customer service management, etc. There is performance measurement for all of the functions which helps the continuous improvement of both SC and organizational plan & strategy. All of these are supported by a base of SC enablers which is the system that helps the whole thing running, for example, IT system, HRMS, and the infrastructure. (Du Toit & Vlok 2014)

Figure 1. Supply chain framework (modified from Du Toit and Vlok, 2014)

2.1.1 Logistics process

According to Frazelle's (2002) framework, there are five key activities: Inventory management, Supply management, Transportation, Warehousing, and Customer Response. They all have their subactivities usually managed by different teams. Inventory Management mainly deals with forecasting of the items, order quantity engineering, planning of those orders, also control policy and deployment of the orders. This is part of logistics as they are directly involved with the material supplies. One of the main activities of logistics is supplies. Sourcing of the materials, supplier's integration, purchase order processing, buying, and payments are the main tasks here. Here the policy for supplier service is also handled. Another main activity is transportation. It handles the shipment, carrier, fleet, freight management. The whole network design is done under this activity.

Lastly, warehousing is a vital activity for logistics. The receiving, put away, storage, order picking, and also shipping of the materials are done in the warehouses (Frazelle 2002).

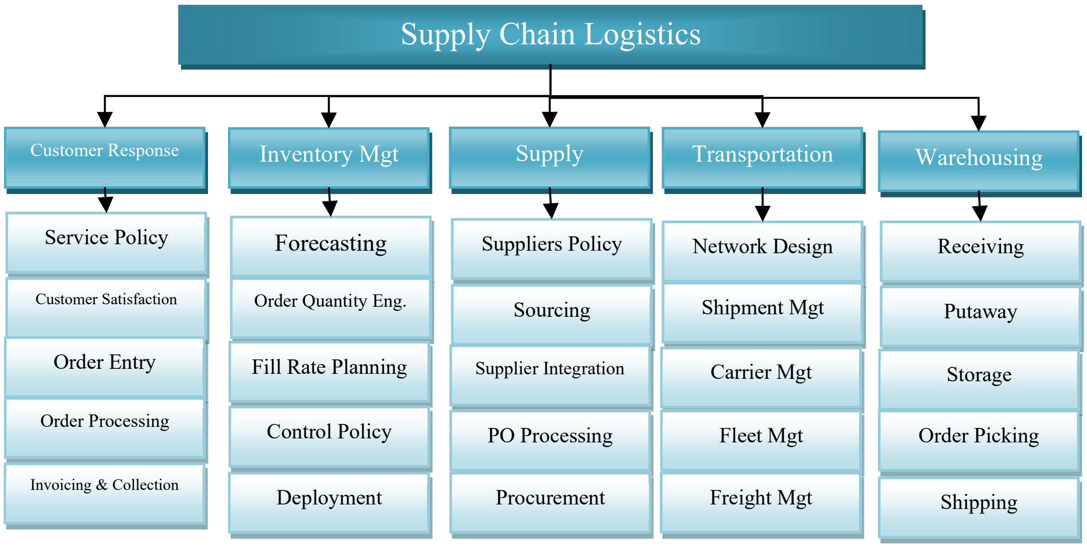

Figure 2. Frazelle's framework for Logistics (modified from Frazelle, 2002)

Walter and Jonson also listed out similar activities. Some of the key logistics activities or functions are (Waters 2003; Jonsson 2008; Rushton et al. 2010):

• Inbound transportation and receiving,
• Warehousing and stock control,
• Material handling and order picking,
• Outward transport and physical distribution,
• Product returns and information management

2.2 SCM Objectives

The main objective of Supply chain management (SCM) is to deliver the right product or service to both internal and external customers in time in an effective way (Smith et al. 2005). Tan divided the objectives into short-term and long-term where a short-term objective is to increase productivity, reducing inventory and cycle time, and long-term objectives mainly focus on increasing customer satisfaction and market shares (Tan et al. 1998). For achieving both short- and long-term objectives effective management needs overall supply chain goals and metrics (Gunasekaran et al. 2001). Metrics are the measurements that indicate the overall performance of SCM, which can be improved by improving the metrics, according to Chen and Paulraj (2004). According to the Supply chain operations reference (SCOR), these metrics have four basic links (Gunasekaran et al. 2001, Chae 2009). The four Meta level processes are Plan, Source, Make and Deliver; aligned in the figure.

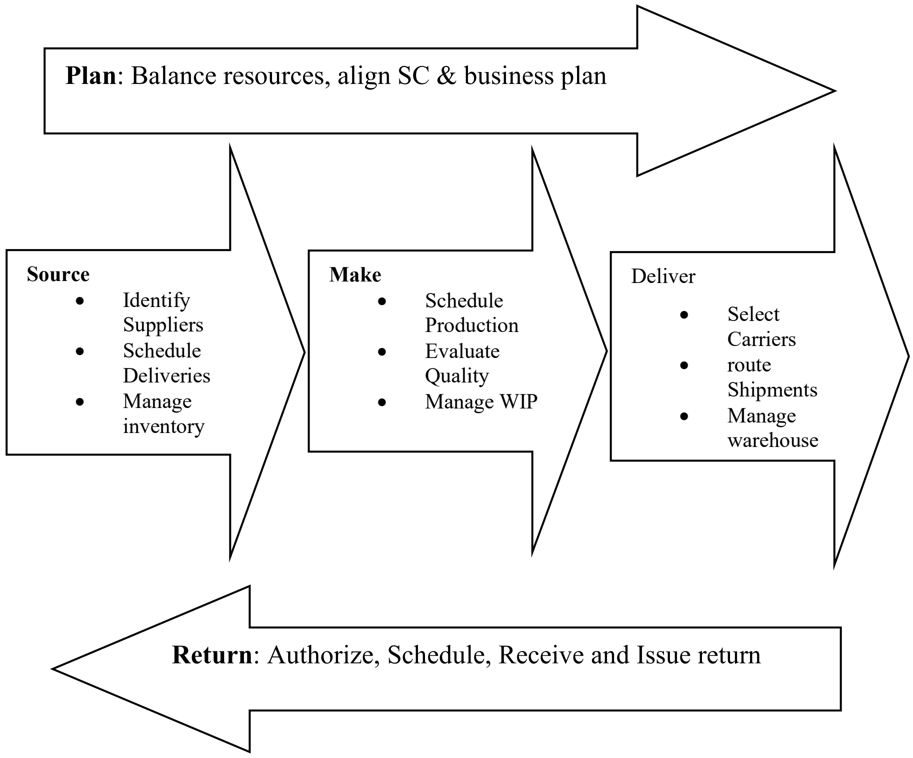

Figure 3. Four Meta processes of the supply chain (modified from Gunasekaran, 2001)

2.2.1 Supply management metrics

From a top managerial perspective, five rights to acquire material or supply, that the management expects the department to achieve from the supply management during procurement of goods and services include:

- Of the right quality
- From the right supplier
- In the right quantity
- At the right time
- At the right price (Burt et al. 1996)

To ensure those rights much Key Performance Index (KPI) are followed for achieving the objective. They are presented in Table 1.

Table 1. Key performance indicators (modified from Siddique, 2016)

Objective	**Metrics/KPI**	**Definition**	**References**
Best quality at a minimum cost	Cost Avoidance	"Spend lower on procured materials"	Huang et al. 2007
	Total cost savings	"The combined amount of money the supply management saves by reducing the Total cost of ownership"	Huang et al. 2007
	Defects per million	"To gauge supplier delivery quality"	Dasgupta 2003
	Percentage of order error rate	"Number of the purchase order with errors divided by the total number of the purchase order in a given period of time"	Kumar et al. 2005; Chao et al. 1993
	Material Acceptance rate	"The amount of material received from the suppliers that are approved for use by the organization"	Hwang. et al 2008
	Material Non-Acceptance rate	"The total number of instances in which suppliers or raw materials are refused by the company due to an error in shipments or defects"	Kumar et al. 2005 ; Axelsson et al. 2002
	Buyer–supplier partnership level	"The level mutual collaboration and trust existing between the supplier and the buyer"	Bhagwat et al. 2007
	Total Number of suppliers used	"The total number of suppliers used by the company drives the efficiency of the supply"	Easton.et al. 2002 ; Axelsson et al. 2002
	Percentage of qualified and certified suppliers	"The number of suppliers that qualified and certified divided by the total number of suppliers being used"	Hwang et al. 2008
Internal Supplies Accuracy	Perfect order fulfillment	"The percentage of orders delivered with the right product to the right place, at the right time, in the right condition, in the right quantity, with the right documentation, to the right customer"	Hwang. et al 2008
	Cycle Time: Supplier order	"The number of business days required to complete a delivery	Bhagwat et al. 2007

	delivery	of materials from suppliers, from the time order is placed until the materials are delivered”	
	On-time supplier delivery rate	“The total number of orders received from a supplier on the committed delivery date divided by the total number of orders”	Hwang et al. 2008; Bhagwat et al. 2007; Chao et al. 1993
	Material Availability	“The total number of orders from the customer or company manufacturing facilities that are delayed because of insufficient or unavailable material in company inventory divided by a total number of orders processed in each period of time, as a percentage”	Hwang et al. 2008
Supplier Relationship	Buyer–supplier partnership level		
	Total Number of suppliers used		
	Percentage of qualified and certified suppliers		
	Cycle Time: Supplier order delivery	“The number of business days required to complete a delivery of materials from suppliers, from the time order is placed until the materials are delivered”	Bhagwat et al. 2007
	Percentage of Sole source Supplier	“The total number of suppliers used by the organization that is exclusive suppliers, divided by a total number of suppliers in a given period”	
	Percentage of Sole source Material	“The amount of material received from exclusive supplier divided by the total amount of materials used”	
	Defects per million		
An uninterrupted flow of materials	Inventory Turnover rate	“The average number of days required to sell and replace the company’s inventory; from the time the inventory is replenished to until it is depleted”	Hwang et al. 2008 ; Gunasekaran et al. 2001
	Inventory Accuracy	“The difference between reported and actual inventory levels as a percentage”	Hwang et al. 2008 ; Gunasekara

			n et al. 2001
	Supplier Fill Rate	"The quantity of supply received from supplier to the required quantity of the order"	Huang et al. 2007
Supplier performance	Buyer–supplier partnership level		
	Quality cost per supplier	"The metric indicates the cost associated with quality of the product or services received from the supplier"	Youssef et al. 1995
	Supplier Fill Rate		
	Supplier order documentation accuracy rate	"The total number of supplier orders received with complete and correct documentation divided by total number supplier orders received over the same period"	Hwang et al. 2008 ; Gunasekaran et al. 2001
Effective material selection	Defects per million		
	Quality cost per supplier		
	Material Acceptance rate:		
Productivity of the supply management resources	The frequency of supplier Evaluation	"The average number of business days elapsed between formal supplier evaluations performed over a certain period"	Kumar et al. 2005; Axelsson et al. 2002
	Average Number of Orders Processed:	"Average number of orders processed by an employee or the organization as a whole in a given period"	Weele 2009
	Supplier order documentation accuracy rate		

2.2.2 Logistics metrics

Logistics has also four main objectives which are focused to be achieved the KPIs i) customer satisfaction, ii) supply chain efficiency, iii) continuous innovation and iv) continuous learning (Wouters and Wilderom, 2008).

The objectives and KPIs of logistics from different works of literature are listed in Table 2 below.

Table 2. KPIs of logistics (modified from Siddique, 2016)

Objective	Metrics/KPI	Definition	References
Increase logistics revenue	Customer Backorder rate	"The number of customer orders delayed in shipment due to the product being out of stock divided by the total orders made in a given period as a percentage"	Fawcett & Cooper 1998
	Average Delivery time	"It is the ratio between the time taken for the shipment to arrive at its destination from the facility to a total number of shipments in a given period"	Fischmann et al. 2008
	On-time arrivals or delivery	"The metric indicates the percentage of a shipment arriving on time on a pre-specified arrival date to the number of shipments"	Fawcett & Cooper 1998
	Delivery consistency	"The metric compares the average transit time of shipments to the promised transit time. The deviation from promised and actual transit times indicates the level of consistency in delivery"	Coyle et al. 2016
	Information accuracy	"Measures indicate the efficiency in data sharing between customer and logistics function, these metrics indicate the percentage of data synchronization, data accuracy, invoice accuracy, etc."	Kelepouris et al. 2006
To minimize cost in the overall physical distribution	Total logistics cost	"The metric indicates the total cost incurred in movement, handling, and warehousing of the goods in the logistics system"	Laird 2012
	Shortage and delay cost	"The metric indicates the cost incurred by the organization due to delay and shortage of materials"	Annadurai 2013
To ensure agility, flexibility, and ability to adapt	Average Delivery time	"It's the ratio between the time taken for the shipment to arrive at its destination from the facility to a total number of shipments in a given period"	Fischmann et al. 2008
	Throughput time	"The metric indicates the duration of time taken to carry a particular or set of operations to deliver the product to the customer"	Gunasekaran et al. 2001

	Upside delivery flexibility	"The metric indicates the time elapsed in days between unplanned event and achievement of continuous delivery performance"	Huang 2013
	Capacity utilization	"The metric indicates the portion of the designed logistics capacity that is utilized during product delivery. The designed capacity varies for different logistics systems"	Waters 2003
To ensure short and reliable delivery times	Average Delivery time		
	Throughput time		
To enhance the total productivity of the resources	Total productivity	"The measure indicates the ratio of total logistics lead-time in product delivery to a total number of resources used, the unit is indicated in terms monetary value"	Waters 2003
	Equipment productivity	"The measure specifies the utilization rate of logistics equipment used in the product delivery, it can indicate either transportation or any other material handling equipment productivity, such as a number of customer visits per van, and weight moved per forklift, total distance flew per airplane"	Waters 2003
	Capital productivity	"The measure indicates the output of the logistics system to the total capital invested, such as a number of goods stored, product delivered, and throughput per each monetary unit of investment"	Waters 2003
	Labor productivity	"It measures one or more activity of logistics to the total personnel's available, such as a number of product deliveries per person, or tons moved per work shift, etc."	Waters 2003
To ensure quality in the delivery of products	Number of customer returns	"The total number of goods returned by the customer due to defects or quality issues. A logistics quality metric that indirectly indicates the customer service level. The target is to have zero number of customer returns"	Lalonde & Pohlen 1996

	Shipping accuracy	"The measure is the ratio of the number of deliveries that have the correct products, quantities to the total number of deliveries done in a given period"	Ross & Rogers 1996
	Number of defects during transit	"The metric indicates the total number of defects per shipment. The goal is to achieve zero defects in all the shipments"	
	Information accuracy		

2.3 Supply Chain Resilience

The word 'Resilience' is used in many disciplinary in different ways but in the same context. For example, in Engineering it means "the tendency of a material to return to its original shape after the removal of a stress that has produced elastic strain" (Merriam-Webster 2007). In the ecological sciences, "the ability for an ecosystem to rebound from a disturbance while maintaining diversity, integrity, and ecological processes" (Folke et al. 2004). Based on the concept of this system, According to Fiksel (2003), there are four major characteristics of resilient systems: diversity, efficiency, adaptability, and cohesion. Finally, in the view of organizational leadership, "More than education, more than experience, more than training, a person's level of resilience will determine who succeeds and who fails" (Dean Becker, Coutu 2002). Therefore, according to Stoltz (2004), creating resilient leaders is the best way to ensure that your organization will prosper in a very chaotic and uncertain future and those resilient organizations consistently outlast their less resilient competitors.

However, like basic engineering, the supply chain does not aim for returning to its original shape following a disruption, adapt into a new configuration that can prevent the disruption or prevent loss from the disruption. Just like the ecology, the concept of adaptability is crucial and supply chains can be considered as a network of living systems.

The concept of resilience in supply chains combines these previous tenets with studies of supply chain vulnerability, defined by Svensson (2002) as "unexpected deviations from the norm and their negative consequences." Also, mathematically, vulnerability can be measured in terms of "risk", a combination of the likelihood of an event and its potential severity (Craighead et al. 2007; Sheffi 2005). Both these definitions have foundations in traditional risk management techniques.

Steven A. Melnyk (2014) from the Department of Supply Chain Management Michigan State University illustrated a visualization of a time series display of supply chain resilience. There are four phases of resilience: avoidance, confinement, stabilization, and return. It also specifies the sequence of events in a disruption, known as the time series signature, as well as the normal system reaction to a typical disruption. To mention a few, inventory levels, cash flow, and asset availability are all factors to consider. T and R are the two most important variables. T stands for the period when a certain event happens, and R stands for the event's relative effect, which may be quantified in dollars, units lost, change in fill rate, or any other statistic that is essential to a company's success. Time (T) and response (R), when combined, are significant because they form inflection points in the time series signature where a state change may be noticed.

The first highlight on supply chain resilience was taken into account in the UK after two events that caused transportation disruption. First were the fuel protests in 2000 and the second one was followed by the outbreak of the Foot and Mouth Disease in early 2001. The study explored the UK's industrial knowledge base about supply chain vulnerabilities and found that: (1) supply chain vulnerability is an important business issue, (2) little research exists into supply chain vulnerability, (3) awareness of the subject is poor, and (4) a methodology is needed for managing supply chain vulnerability (Cranfield University 2003).

Based on this empirical research, Christopher and Peck (2004) developed an initial framework for a resilient supply chain. They asserted that supply chain resilience can be created through four key principles: (1) resilience can be built into a system in advance of disruption (i.e., re-engineering), (2) a high level of collaboration is required to identify and manage risks, (3) agility is essential to react quickly to unforeseen events, and (4) the culture of risk management is a necessity. Characteristics such as agility, availability, efficiency, flexibility, redundancy, velocity, and visibility were treated as secondary factors.

Researchers at the Massachusetts Institute of Technology (MIT) analyzed many case studies of supply chain disruptions and noted that disruptions can also bring unexpected opportunities for success, as shown by three examples (Sheffi 2005). Dell used the West

Coast port lockout in 2002 as an advantage to stimulate demand for LCD monitors that they could economically ship via air freight, displacing bulkier CRTs. Los Angeles Metrolink transit system increased its ridership by 20-fold immediately following the January 1994 Northridge earthquake. FedEx took the opportunity of the strike at UPS in 1997 by filling unmet demand.

Such disruptions “can offer an opportunity to impress customers and win their loyalty” (Knemeyer, Corsi, and Murphy 2003), and “successful recovery and adaptation to new market forces can lead to competitive advantage” (Rice and Caniato 2003).

The function of relational capabilities/competencies in achieving Supply Chain Resilience (SCRES) has been understudied, according to Kochan and Nowicki’s (2019) literature review. Among the relational capacities examined are connection, collaboration, and integration (Wieland and Wallenburg, 2013); commitment, standards, and obligations (Johnson et al., 2013); adaptation and interdependence (Mandal, 2013); and coordination (Scholten and Schilder, 2015).

SCRES' Mechanisms (M); according to Denyer et al. (2008), a particular method is needed to produce a specific outcome. The resource-based view (RBV) (Wernerfelt, 1984; Barney, 1991) is a standard theoretical lens used to explain SCRES. In SCRES analysis, RBV is used to analyze relationships between specific methods, abilities, and outcomes. To address the criticism that RBV is static, SCRES authors use theories such as dynamic capabilities theory (DCT) (Teece et al., 1997), contingency theory (Lawrence and Lorsch, 1967), systems theory (ST) (Von Bertalanffy, 1950), and relational view (RV) (Dyer and Singh, 1998).

Mandal (2013) used RV, RBV, and DCT to explore the relationships between relational resources/competencies and developed a theory-driven conceptual model that defines SCRES as a complex capability. RV was used by Wieland and Wallenburg (2013) to define the relationships between social competencies and resilience parameters. Ponomarov and Holcomb (2009) used DCT as an extension of RBV to show the relationships between logistics capacities, SCRES, and long-term competitive advantage. RBV and DCT were inadequate for determining contingencies that captured the capabilities and resources, so Brandon-Jones et al. (2014) extended RBV to contingency theory. Blackhurst et al. (2011) applied RBV to ST, proposing that the effect of disruptions on an SC varies depending on the degree of SCRES. To investigate SCRES and develop an awareness of SCRES, Tukamuhabwa et al. (2015) proposed a complex adaptive systems theoretical tool.

2.4 Risk Management

Resilience is a new concept that differs from traditional risk management. Risk analysis techniques are playing a major role in corporate decision-making since the 1970s, especially when combined with financial models (Hertz and Thomas 1983). First, it defines all possible results of a project by calculating and comparing the potential returns against the potential risks of the investment (Carter 1972). Currently, the leading approach to Enterprise Risk Management comes from the Committee of Sponsoring Organizations of the Treadway Commission (COSO 2004).

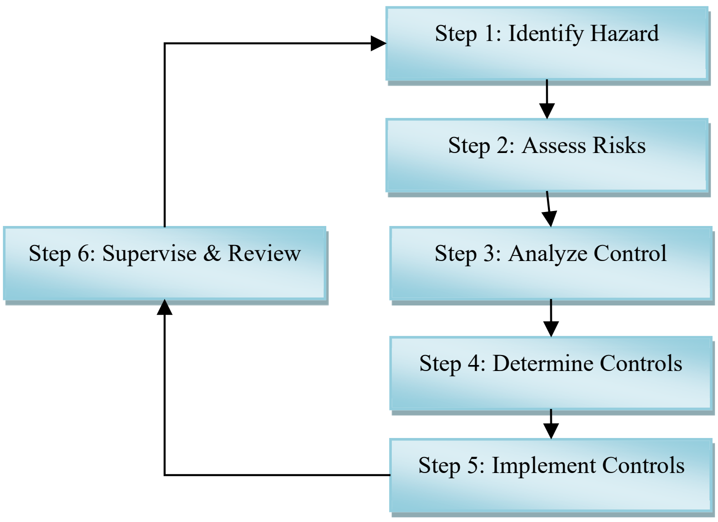

Figure 4. Operational risk management process (modified from Manuele, 2005)

A typical view of the traditional risk management process is shown in figure 4. It's a cycle of identifying the hazard, then assess the risks, analyze controls, choosing controls, implementing controls, and finally review which is continuous improvement giving feedback to step 1. The risks can be quantified either by historical data or sometimes need more assumptions based on the data and subjective information as well. But it will be challenging to apply this to each link in a global supply chain for every possible disruption.

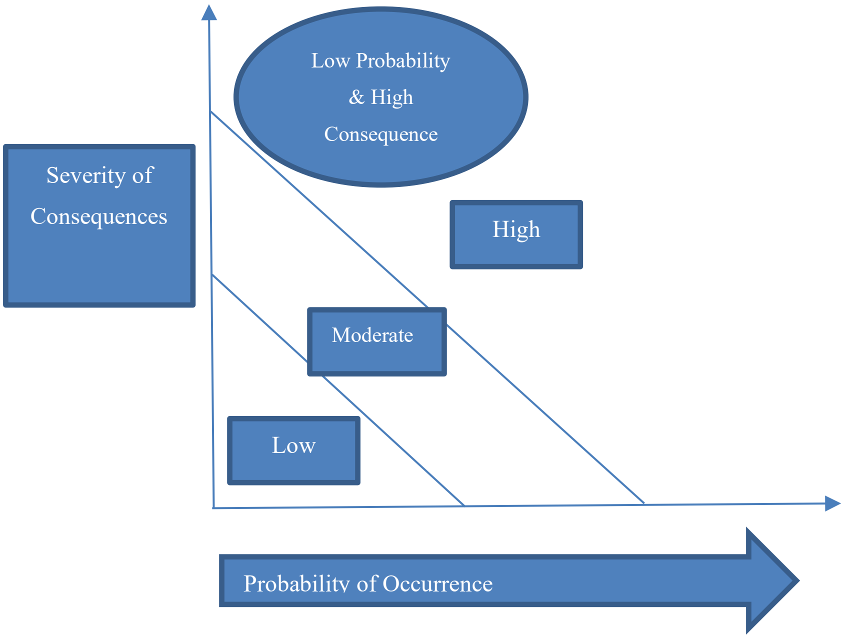

Figure 5. Traditional risk management assessment (modified from Manuele, 2005)

Risk assessment is a critical step in the risk management process (figure 5) because the estimated severity of the event (if occurs) calculated is based on that probability of the assessment. The greatest weakness of risk management is its inability to adequately characterize low-probability, high-consequence (LP/HC) events, marked in the figure. (Kunreuther 2006).

Additionally, the traditional risk assessment approach cannot deal with unforeseeable events which are its biggest weakness. The concept of supply chain resilience can support the existing risk management system and counter the weakness. Enabling the supply chain to survive unforeseen disruptions can give a huge boost to competitive advantage (Pettit et al 2010).

2.5 Strategic Resilience

The most effective part of the concept of resilience is that it utilizes strategies that do not require exact quantification. It doesn't need a complete enumeration of possibilities or assumptions of a descriptive future like traditional risk analysis. Strategic resilience makes it less brittle and more adaptive to change through 5 ways according to Pettit et al. (2013):

1. Supply chain design
2. Focus on business process management to enhance capabilities across the supply chain
3. Visibility to demand and supply throughout the supply chain
4. Supplier and customer relationship management
5. Infusing a culture of resilience

This strategy can be divided into two parts. One is proactive strategies and the other is reactive strategies (Belhadi et al. 2021). The strategies according to Belhadi that go under these two categories are described next.

2.5.1 Proactive Strategies

Digital Technology

We now have high accessibility, data quality, and clarity thanks to modern technology. As a result of these benefits, IoT, digital twins, blockchain technology, and other technologies may help to improve supply chain durability (Hofmann et al., 2019). Industry 4.0 promotes capability development hence supply chain resilience. Industry 4.0 is based on the concept that smart systems and autonomous processes can automate some activities and choices. However, there is a minor danger of losing key skills such as the capacity to be flexible, agile, and robust in the face of supply chain disruptions. Because of capacity improvement and new talent development, these smart systems may contribute to improved supply chain resilience (Ralston & Blackhurst 2020). Handfield et al. (2019) used a contextual method to explain the changing landscape of procurement analytics, drawing on three references (interviews from executives, a study of new and emerging infrastructure channels, and a survey of chief procurement officers). Even though they discovered that procurement analytics will continue to improve, their research revealed that advanced procurement analytics remain underutilized, and data quality and consistency issues are preventing significant advances in analytics. They agree that current ad hoc methods to capturing unstructured data should be replaced by a specific data governance framework and that organizations should adopt a reliable, systematic method to acquiring and maintaining trusted organizational data focused on internal expenditure reviews and contract databases. The report also cited a variety of accessible channels that could not always be merged as a source of complexity. Lechler et al. (2019) use a Delphi analysis methodology to see how real-time data collection reduces SCM uncertainties in real-world situations, addressing the problems of gathering suitable, timely, and accurate data under VUCA (volatility, uncertainty, complexity, and ambiguity) conditions. The "uncertainty paradox" is worth remembering for researchers and clinicians: on the one side, more real-time data may be a valuable method for minimizing supply chain uncertainty, but such data may often create new complications, defined as data-related uncertainty.

The focus is on inference rather than explanation centered on existing theories, as shown by leading journals in the field of machine learning (an expansion of AI) in supply chain networks. Machine learning is a term that describes a system or algorithm that learns without being explicitly programmed and recognizes patterns that make for real-world prediction. Supply chains, according to Handfield et al. (2019), could move from optimization to prediction, which supply chain analysts may look forward to. This will almost definitely necessitate a move toward more inductive analysis methods in SCM. According to Stank et al. (2019), concentrating further on robust execution and application of inductive methods is likely to lead to some of the recent demands for more managerial relevance to supply chain research.

Automation

Modern automation allows a firm to reduce dependencies on humans which helps to reduce uncertainties. Thus, a firm can enhance resilience proactively (Hofmann et al., 2019). Morenza-Cinos et al. (2019) use design science methods and a novel algorithm to show that an autonomous robot can do stock-taking using RFID for object-level recognition even more effectively and reliably than human operators using RFID handheld readers. Since the robots for inventory taking had to adopt human-assisted identification protocols, the authors discovered certain untapped potentials for their robots. While a completely autonomous approach could yield better outcomes, further analysis is needed to solve possible contradictions between an idealized technological and digital environment and the social dimensions of human life.

Self-steering supply chains are supported by the automation of inter-organizational processes. As a consequence of cost pressure, businesses are under pressure to adapt their procedures and find new ways to save money. Although businesses began automating their standardized manufacturing procedures in the 1970s (Kagermann, 2015), the majority of merchandise handling and distribution is still performed by hand. This nonstandardized method may be semi-automated by providing service technology to employees or fully automated by utilizing robotic solutions. Electronic external freight storage and fulfillment, in addition to remote processing and intra-logistics, is increasing momentum. Even though completely autonomous trucks pose technical and legislative hurdles (Flämig, 2016), automated last-mile transportation technologies such as autonomous drones or distribution robots have been evaluated in pilot projects, highlighting the need for further research and growth (Jennings and Figliozzi, 2019). Morenza-Cinos et al. (2019) demonstrate how intra-logistics operations can be managed using robotics. The architecture of the human-machine interface would be crucial in this situation (Gorecky et al., 2014).

Risk Management Integration

A firm can make the risk management system integrated with the stakeholders related to the firm. Especially, supply chain integration will give it a better resilience to foresee many incidents (Zhu et al., 2017). The supply chain must cope with certain risks, according to Integrated supply chain risk management's (ISCRM) fundamental assumption. As a result, the first big issue of ISCRM is identifying risk factors (Lavastre et al., 2012). Supply chain challenges are generally classified into two categories: operational risks and disruption risks (Chen et al., 2012; Tang, 2006). Operational risks are linked to supply-demand coordination that results from inadequate or failed processes, people, and systems (Zhao et al., 2013). Disruption risks are environmental challenges that affect the overall business climate across industries (Ritchie and Marshall, 1993). There are also Regulatory risks stemming from changes in rules and regulations, infrastructure risks stemming from human-caused issues such as strikes and industrial accidents, and catastrophic risks such as terrorist attacks, epidemics, and floods are all examples (Wagner and Bode, 2008). Organizational risks i.e. the focal organization's production-distribution risks, industrial risks including demand/market risks, supply risks, and competitive/technological risks are (Rao and Goldsby's 2009) typology of supply chain risks, which ranges from the organization itself to the environment affecting the whole supply chain. Upstream from supplier production, downstream from customer demand, and internally from the focus firm's procurement and distribution processes are the three primary causes of supply-demand volatility in a supply chain (Germain et al., 2008). In addition, all supply chain members face competitive/technological challenges, which are operational hazards. Competitive and technological challenges, manifested as the scale of unforeseen technological advances, can render existing technology redundant quickly.

ISCRM is a collaborative effort between major supply chain firms to ensure the chain's long-term longevity and profitability (Tang, 2006). To help minimize competitive/ technical risks, Tatikonda and Stock (2003) proposed three dimensions of SCI: collaboration, teamwork, and cooperation. These dimensions refer to Walton's (1966) three fundamental components of the relationship: information sharing in decision-making, the structure of inter-unit relationships and joint decision-making, and attitudes toward the other unit. Information integration, institutional integration, and relational integration are three distinct facets of SCI, according to Leuschner et al. (2012), both of which are focused on a common definition. Leuschner et al. (2012) directly point out the interrelated behaviors for ISCRM. ISCRM aims to ensure their continuity and viability, which is close to SCRM's task of performance preservation. “Key supply chain organizations working together” applies to key members facilitating Supply Chain Integration (SCI), which is a mechanism for main supply chain actors to cooperate to organize intra- and inter-organization activities. So, first and foremost, it's critical to comprehend who are primary supply chain members, i.e., the scope of SCI, which identifies the types and numbers of companies that make up an integrated supply chain (Mentzer et al., 2001). Frohlich and Westbrook (2001) categorize multiple SCI scopes and identified five scopes: inward-facing, periphery-facing, supplier-facing, customer-facing, and outward-facing. Looking at SCI scopes ranging from dyadic integrations to extended integrations affecting more than three classes, as proposed by Fabbe-Costes and Jahre (2008), who describe it as the focal company interacting with both upstream and downstream stakeholders, but in different ways. Consequently, it can be measured twice if it addresses both limited dyadic downstream integration and limited dyadic upstream integration.

Most ISCRM papers, according to Kache and Seuring (2014), assess focal firm efficiency, entire supply chain performance, or both. Some articles assess the performance of both businesses (e.g., Bhaskaran and Krishnan, 2009; Wei et al., 2012). It's also important to know what continuity and profitability or the performance dimension entail. The two sources are "continuity" and "profitability." Continuity refers to the maintenance of strategic advantages such as customer intimacy, operational excellence, and product leadership (Treacy and Wiersema, 1995), and it applies to four risk sources:

demand/market risks for customer intimacy, supply risks, internal risks for operational excellence and competitive/technological risks for product leadership. The term "profitability" applies to a company's overall commercial growth, which includes both business and financial results (Flynn et al., 2010). The short-term goals of ISCRM are to maintain cash flow, return on expenditure, and gross margin on sales, while the long-term goals are to increase market share and income (Li et al., 2006).

Human Intelligence

Human judgment is very important for proactive decision-making to avoid risks. There is much information available to analyze which can help to monitor and control the checkpoints for the supply chain (Blackhurst et al., 2005). It is important to see people keep an eye on key points in the chain. In contrast to the enormous amount of intelligence available today, humans, on the other side, have a few skills as well. The majority of supply-chain intelligence must be automated, but certain conditions for human interaction must still be fulfilled.

According to Blackhurst et al. (2005), better global intelligence monitoring and interpretation would be feasible for monitoring supply chain disruptions. One simple example is the West Coast port strike, which has been discussed in the media for at least six months, but only a few companies have implemented a strike contingency strategy (Blackhurst et al., 2005). These enterprises were put off balance when the strike occurred, causing supply chain disturbances.

A lot of work has been done in the area of computer science on machine language rapid translation. The issue is a lack of effort to gather valid, timely, and dependable data. Intelligent network agents are a relatively new technology that has the potential to be useful for data/text mining and disruption-related intelligence searches on the internet. Intelligent agents may be used to thoroughly search the web. This would not be a simple mission. Menczer (2003) estimated that Google had over 1.6 billion URLs indexed at the time of his research. According to Menczer, the web is complicated, with pages being added, deleted, modified, updated, and linked at an unprincipled pace. Search agents are used in the following forms on the internet: According to Boureston (2000), intelligent officers can immediately travel to several places, find and collect relevant data, and deposit it for processing. Menczer (2003) suggests an evolutionarily multi-agent scheme in which each population of peers learns to respect hyperlinks and the population as a whole attempt to secure all promising places. This is then used to build MySpiders, a public web mining platform, which is multi-threaded as a Java applet.

The use of these agents would undoubtedly help to minimize disruptions; nevertheless, further research is required to answer the questions "How, Where, When, and When," which global logistics managers often ask. These methods may be used to gather knowledge about potential and previous disruptions. A series of experiments using multi-language search agents on archived news/information sources and then linking them to announced disruptions, for example, may provide managers with useful preliminary data. This form of event study would be particularly helpful if patterns can be observed and can be used to identify possible disturbances. The study would almost definitely have to restrict the types of disruptions to a limited amount, if not just one, due to the feasibility of such an undertaking. Furthermore, although the search agents may be inefficient in certain types of disruptions such as fires, they will be successful in others e.g., strikes Blackhurst et al., 2005).

Finally, although danger indexes are a discovery problem, they are also critical to the redesign phase. Supply-chain risk estimates are often based on stagnant or seldom-changed management expectations (e.g., Zsidisin 2003). Despite the benefits of these approaches, also need to develop-

(a) more accurate risk models and
(b) dynamic or real-time strategies.

Factors such as the global calendar, strike arrangements, volume and capacity, environmental conditions, and so on would be included in the creation of complex risk index instruments by area/port/location. Several executives mentioned during the interview process that US-based companies are US-centric in their thinking and do not understand variations in national holidays and observances. Supplier health indices, OEM health indices, and supply-chain risk controls, which may include risk tolerance, vulnerability, and the potential to handle disruptions, are often of interest. Early warning signs of impending or growing risks would be a key feature. These models may be used to make initial supply-chain choices as well as recognize "red flag" locations that needed to be resolved. These models would be particularly useful if they were web-based and could be distributed easily to supply-chain customers and keep the system up to date.

Many interviewees said that supply-chain risk perception should become a part of day-to-day supply-chain operations, as this would allow them to do so (Blackhurst et al., 2005).

2.5.2 Reactive Strategies

Collaboration

The companies that are connected with the supply and delivery should collaborate so that they can minimize the loss and also be proactive for the occurrences in the future (Zhu et al., 2017). Over the same time frame, Kim et al. (2008) discovered two procurement techniques: looking for new suppliers and collaborating with an existing supplier. High competitive/technological risks are beneficial to the focal firm's quest and partnership, while low competitive/technological risks are detrimental.

Procurement is a vital part of the supply chain, which also can be affected by disruptions. It can stop the money flow and cause huge losses to the stakeholder firms. High demand/market volatility decreases the focal firm's chase and collaboration; as the focal firm's reliance on the incumbent supplier grows, the focal firm reduces search and increases collaboration; and the implementation of these procurement techniques improves the incumbent supplier's responsiveness. Terjesen et al. (2012) proposed that supply chain coordination operations and modularity-based production methods can help manufacturing companies accomplish both integration and differentiation using distinction-integration duality (MBMP). They discovered an inverse U-shaped relationship between SCI and operational quality, as well as the fact that higher SCI and MBMP levels result in better operational output, particularly when industrial risks are large. Their results and research point to two big problems that aren't addressed in this research stream: first, supply risks could coexist with the other two industrial risks, necessitating further research into their interactions. Second, SCI alone might not be the most efficient way to mitigate supply risks. In the future, any approach that has a positive joint impact with SCI in terms of reducing supply danger should be investigated.

Big Data Analysis

Supply chain information systems can collect and extract valuable insights from real-time data and provide effective support to timely decision-making (Belhadi et al., 2019). In the future, big data in supply chains would be a valuable research method (Richey et al., 2016; Hofmann and Rutschmann, 2018). Sanders et al. (2019) mention crowdsourced data as a groundbreaking data tool open to supply chain analysts, but only a few examples have been published so far (Sternberg and Lantz, 2018). Data accuracy is becoming extremely important as statistical models become more general, as Lechler et al. (2019) point out. It also raises the need for algorithms that can cope with data sets that aren't intended for science research, such as those with missing or inaccurate data points. Big data is not a goal in and of itself. Its future usefulness will only be realized if it is used as a means to help decision-making processes (Gandomi & Haider, 2015). To address this issue, academics and practitioners have developed several data processing and computational analysis techniques and processes dubbed Data Analytic, practitioners from the artificial intelligence, computer, and database communities to derive actionable grasp from large amounts of scalable and diverse info (Chen et al., 2012). There are many computational methods to choose from while working on a big data project. Big Data Analytic (BDA), according to (Sivarajah, Kamal, Irani, & Weerakkody, 2017), will improve decision-making and increase operational performance by extracting meaning from data for various styles of analytic issues, such as descriptive analytics, predictive analytics, and prescriptive analytics.

Descriptive analytics generate daily reports, ad hoc reports, and warnings utilizing market intelligence software to gain insight into the actual condition of a business situation (Joseph & Johnson, 2013; Sivarajah et al., 2017). Descriptive analytics is a backward-looking methodology that reveals ‘what did' or warns of what is about to happen using a subset of techniques. In addition to traditional monitoring and scoreboards, Banerjee, Bandyopadhyay, and Acharya (2013) identify a dashboard as a type of application in which an enterprise routinely generates multiple indicators or measurements dependent on data to track a process over time. To leverage the descriptive analysis of systems, additional techniques such as Advanced Data Visualization (ADV), data mining, and advanced statistical analysis are listed. Text, recording, and other interactive analytics are among the tools emphasized to promote descriptive analytics (Gandomi & Haider, 2015). These technologies are needed to recognize the need for extracting information from emails, unstructured audios, and video sources, linking them to specific decision-making processes, and ultimately cultivating a data-driven decision method.

Analytical inquisitiveness investigates "why this occurred." An inquisitive analysis is usually aided by descriptive information output or supplementary data obtained utilizing descriptive analytics techniques to reveal the root causes of an issue (Banerjee et al., 2013). In general, investigative analytics techniques such as generalization, association, sequence pattern mining, and clustering analytics aim to expose the possible or recessive laws, features, and relationships (such as dependence, resemblance, and correlations) that occur in the data (Cheng et al., 2018). Modeling Statistics, Query Tools, Spreadsheets, OLAP Tools, and Decision Trees are examples of other strategies (Chen et al., 2012).

Predictive analytics aims to offer foresight and glimpses into the future. Predictive analytics uses forecasting and mathematical modeling to provide insight into “what is going to happen” in the future using controlled, unsupervised, and semi-supervised learning frameworks (Gandomi & Haider, 2015; Sivarajah et al., 2017). According to Cheng et al. (2018), there are two types of predictive analytics strategies. The first is predictive analytics-oriented strategies, which employ mathematical models to infer and forecast unknown knowledge as well as induce and interpret current data. Multinomial logit models (Sivarajah et al., 2017), regression strategies (Gandomi & Haider, 2015), K-nearest neighbor (KNN), and Bayesian (Cheng et al., 2018). The second includes information exploration KD-oriented approaches, which are data-driven and do not necessitate the identification of hypotheses and issues ahead of time. Machine learning strategies such as Neural Networks (NN), Multiple Backpropagation (MBP), Self-Organizing Map (SOM) (Sivarajah et al., 2017), rough package, genetic algorithm (GA), association law, support vector machine (SVM), generalized sequential pattern (GSP), and others are also included in this group (Cheng et al., 2018).

Prescriptive analytics (Sivarajah et al., 2017) optimizes process models dependent on the performance knowledge of predictive analytic models. Prescriptive analytics is often concerned with the concept of a series of judgments that should be made based on the analysis of cause-and-effect relationships between analytic outcomes and business process policies (Banerjee et al., 2013). Discrete Choice Modeling, Linear and Non-linear Programming, and Value Analysis were listed by some authors despite their complexity (Banerjee et al., 2013; Sivarajah et al., 2017). Furthermore, “what if” simulators include information regarding the likely solutions that a company can introduce to improve the operation (Banerjee et al., 2013).

Business Continuity Plan

A business continuity plan is needed for the recovery and also prevention from potential disruptions. Barnes (2001) covers a systematic description of BCP where his perspective on business continuity planning is that, through integrating formalized processes and resource information, businesses may rebound from a crisis that disrupts operations. From the viewpoint of the finance industry, Elliott et al. (1999, p. 48) define business continuity planning as "planning that defines the company's vulnerability to internal and external risks and synthesizes hard and soft assets to provide successful protection and recovery for the organization, thus ensuring competitive advantage and value system credibility". Shaw and Harrald (2004) recently recognized BCP as an important aspect of business continuity management, which consists of business practices that emphasize and guide the decisions and activities necessary for a company to avoid, resolve, plan for, react to, restart, rebuild, repair, and transition from a crisis. Ericson (2001) discusses the need for organizations to develop structured BCP structures, noting that management's perceived value for incorporating BCP has increased significantly. According to Digital Research Inc. (2002), three out of every four businesses that have preparations in motion to cope with such disturbances have reviewed their plans in light of the events of September 11, 2001. Initially, BCP's emphasis was on information technology (Savage 2002). However, it is gradually realized that maintaining the flow of inbound goods and services as inputs to output is one of the most important practices inherent in risk management (Barnes 2002, Gilbert and Gips 2000). (Burt et al. 2003). Gilbert and Gips (2000) have looked at the components that make up the formal BCP scheme which consists of four main components: risk identification, risk assessment, risk ranking, and risk management.

According to Zsidisin et al., 2005, an efficient supply chain continuity preparation strategy is built on a foundation of awareness, avoidance, remediation, and information management. increasing public knowledge. When a company knows that it is at risk of supply chain disturbances and understands the possibly serious repercussions of those disruptions, it develops awareness. Internally, at various layers of management, this knowledge must grow for capital to be distributed and effective procedures and tools to be developed and applied to handle the danger. It's also important to spread this information across the supply chain, to consumers and retailers, so that their assistance can be engaged in the risk-management campaign. Preventing production interruptions, the avoidance mission is the second most critical task in BCP for the inbound supply chain. The aim is to lower the risk and/or severity of supply chain disturbances. Prevention consists of four main processes (Zsidisin et al., 2005):

1. Risk identification: identifying the reasons and origins of future supply chain delays.
2. Risk assessment: for each trigger or source of possible disturbances, determining the probability of incidence and the effect the incident would have on the enterprise.
3. Risk treatment: identifying and prioritizing the causes/sources of future market disturbances, as well as designing techniques for minimizing their probability and/or mitigating their effects.
4. Risk management: ongoing monitoring of supply chain trends that can raise or decrease threats. Changes in the economic or political climate, changes in commodity markets, or the position of particular vendors are both possibilities.

Reducing the incidence of danger, Remediation is the third task in the continuity preparation system. Although the company takes precautions to minimize its exposure during the mitigation period, danger cannot be entirely minimized, and supply chain delays cannot always be prevented. As a result, businesses need a plan of action to implement to rebound from a disturbance. The company should think about how it can shorten the disruption's length, reduce its effect on the market, and determine the tools required to carry out the strategy ahead of time. Encouragement in information management is Zsidisin's (2005) final component. When a supply chain is disrupted, the company must learn from the situation. This necessitates a post-incident audit that highlights key lessons learned—what went well, what went wrong, and the outcomes of the remediation effort—as well as input to the early stages of the continuity preparation phase. The goal here is to benefit from supply delays since they indicate that current preparations and contingencies might not be sufficient.

According to Zsidisin (2005), at least two problems need managers' consideration from a tactical standpoint. The first is the development of resources to assist with the BCP framework's first two tasks: raising consciousness and preventing damage. A good range of metrics for evaluating the firm's vulnerability to supply chain danger and its preparedness to cope with the risk is a basic prerequisite for successful BCP for the supply chain. Such tools aid in raising supply chain risk perception while also serving as a starting point for risk management. Supply chain risk/BCP audits are one form of instrument. The development and refining of such audit instruments would aid managers in identifying their successes and shortcomings, as well as prioritizing their behavior. Metrics for BCP are a second topic that should be addressed by management. Managers and companies use metrics to collaborate, teach, and direct interest in any organization (Magretta and Stone 2002). Supply chain management should concentrate on developing indicators that capture, communicate, and track the level of supply chain danger, the dollar effect of such risk, and the relative costs/benefits achieved from the use of relevant BCP practices and procedures.

Inventory Management

A reserve capacity in the inventory can give a very good backup from the disruptions (Lücker et al., 2019). The usage of risk mitigation inventory (RMI), known as speculative capacity, and reserve capacity, also known as reactive energy, has been studied in a variety of environments, including multi-product newsvendors (Reimann 2011), sudden market spikes (Huang, Song, and Tong 2016), and heavy-tailed production (Biçer 2015). These papers are focused on Cattani, Dahan, and Schmidt (2008)'s work in the fashion industry, where they include a general solution protocol for models with speculative and reserve potential.

When demand projections were revised using an additive or multiplicative method, Biçer and Seifert (2017) created an analytical model that enables inventory and capability levels to be optimized over time assuming that there won't be any supply disruptions, taking into account both the market danger and the disturbance risk at the same time. In the face of supply chain instability possibility, Tomlin (2006) explores dual procurement and reserve capability scenarios. His model is built on a more costly but more reliable supplier and a less expensive but less consistent supplier. Under stochastic demand, he characterizes high-level risk reduction tactics but does not optimize RMI and reserve capability decisions together. Lücker and Seifert (2016) investigate a model in which a pharmaceutical company decides optimal RMI levels under deterministic demand and supply chain disturbance risk. Further linked papers (Parlar and Perry 1996; Gürler and Parlar 1997) concentrate on the function of dual sourcing in minimizing disturbance danger under deterministic demand. Lücker (2018) added to the literature stream by jointly optimizing RMI and reserve capability levels under stochastic demand and deriving novel systemic insights.

Multiple scholars have investigated the effect of supply disturbances on supply chain networks (Berger, Gerstenfeld, and Zeng 2004; Ruiz-Torres and Mahmoodi 2007; Yu, Zeng, and Zhao 2009; Li, Wang, and Cheng 2010; Liberatore, Scaparra, and Daskin 2012; Sarkar and Kumar 2015; Schmitt et al. 2015; Niknejad and Petrovic 2016). Schmitt et al. (2015) investigate the function of inventory in a multi-location supply chain to protect against supply chain disturbances. Liberatore, Scaparra, and Daskin investigate the dissemination of disturbance in a network (2012). A decision tree methodology is presented by Berger, Gerstenfeld, and Zeng (2004) and Ruiz-Torres and Mahmoodi (2007) to help assess the optimal number of suppliers under disturbance danger. The authors of Li, Wang, and Cheng (2010) balance a firm's sourcing strategy with its pricing strategy when it is exposed to supply chain disruption danger. Yu, Zeng, and Zhao (2009) investigate dual sourcing decisions for non-stationery and price-sensitive demand in the face of disturbance danger. Sarkar and Kumar investigate behavioral causes in multi-echelon production chains that are vulnerable to supply chain disturbances (2015). They discovered that disturbances in the supply chain could result in higher-order fluctuations than in the base case without disruptions. Niknejad and Petrovic (2016) suggest a complex fuzzy-model-based risk assessment approach for global production networks.

The subject of supply chain resilience has risen to prominence as a result of high-impact events, such as the global pandemic of covid19 or the nuclear tragedy in Japan. The ability to create resilient supply chains is becoming more difficult for practitioners (Snyder et al. 2016; WEF 2013). Supply chain problems may have a significant effect on a company's financial results. Hendricks and Singhal (2005) quantify the impact of supply chain disturbances on long-term market price results using an analytical methodology. They discovered that the typical irregular stock return after reporting a supply chain disruption is about 40%. They looked at data from 1 year before the disruption to 2 years after the disruption.

Companies also create supply chain flexibility leveraging risk mitigation inventory (RMI) and reserve resources to minimize the negative effects of supply chain disturbances (Tomlin 2006). RMI (Simchi-Levi, Schmidt, and Wei 2014; Lücker, Chopra, and Seifert 2018) is extra inventory that is intended to satisfy consumer demand in the case of a supply chain interruption. It's not the same as the operating safety stock, which is held to deal with demand volatility. Chopra and Sodhi (2004) described reserve capacity as "reserving free capacities that can be used for output in the event of a supply chain disruption." Lücker and Seifert (2016) defined reserve capacity as "reserving free capacities that can be used for production in the event of a supply chain disruption." Consider a pharmacy firm like Roche, which makes life-saving cancer medications like Avastin. The manufacture of the drug's biological compound is subject to significant threats, such as biological contamination at a manufacturing facility or a burn, which could result in the facility being shut down for many months. After an event like this, the manufacturing site will only be utilized after receiving governmental permission, which can take a long time. In 2016, Roche produced 6.8 billion CHF in revenue from this medication. A high-profit margin provides the company with the potential to build up RMI and/or reserve resources, in addition to the regulatory obligation of consistently supplying medications to the patient. Lücker (2018) set out to figure out how to make the most use of RMI and reserve power to cope with disturbance danger at a single location under stochastic demand, to figure out what factors contribute to higher RMI or reserve capacity levels. The reserve capability has fixed costs for reserving it, as well as emergency processing costs, which are borne while the capacity is mobilized and an expense for stocking out.

2.6 Intertwined Supply Network

Ivanov and Dolgui (2020) provided a fresh perspective in SC resilience research by demonstrating that resistance to exceptional disruptions must be evaluated on a viable scale. The Intertwined Supply Network (ISN) as whole offers services to society that is needed for long-term survival from their positions of resilience. They used a dynamic game-theoretic model of a biological system that resembled the ISN to demonstrate viability development. Stability is the ability to return to the previous state after any incident and continue the process. (Ivanov and Sokolov 2013; Demirel et al. 2019). Robustness is the ability to tackle a disturbance and continue with the planned process. (Nair and Vidal 2011; Simchi-Levi, Wang, and Wei 2018). Then comes resilience which is the ability to stand against the disruption and recover the performance. (Spiegler, Naim, and Wikner 2012; Hosseini, Ivanov, and Dolgui 2019).

If we consider supply chain resilience at the survivability level, we have to take into account, the concept of viability. Viability can be defined as the ability to survive meeting all the requirements in a changing system (Beer 1981). Ivanov and Dolgui adapted the ecological model into supply chain resilience for gaining viability and introduced

“Intertwined Supply Network (ISN). According to them ISN ‘encapsulates entireties of interconnected SCs’ which makes the supply chain secured from the societies impact in the market for both goods and services (Ivanov and Dolgui 2020). They also defined the differences between resilience and viability, which are-

• Resilience deals with a closed system whereas viability deals with an open system.
• The structure of resilience is static and for viability it’s dynamic.
• The analysis for resilience is disruption driven and viability analysis is behavior-driven mainly.
• The subject of analysis for resilience is discrete and singular disruption reaction but for viability, the subject is a continuous evolution and balancing disruption reaction.
• The main target of the analysis in resilience is performance and for viability the main target is survival.
• The analysis is fixed timed in resilience but in viability, it’s not.
• In resilience, the object of analysis is a linear supply chain system and in viability, the object is an intertwined supply network.

So mainly the principle of ISN is co-evolution and co-creation which does not replace resilience but under uncertainty, it increases the quality of risk analysis.

2.7 SCRAM Assessment Tool

According to Pettit et al. (2010), there is a study deficit in relating vulnerabilities and risks to mitigation strategies. Resilience was described by Fiksel (2006) and adapted by the Council on Competitiveness (2007) as an enterprise's ability to thrive, adjust, and evolve in the face of turbulent change, based on foundations in life and social sciences. Vulnerabilities (fundamental factors that render an organization vulnerable to disruptions) and Capabilities (qualities that allow an enterprise to predict and withstand disruptions) were suggested to be the two structures that makeup Resilience (Pettit et al. 2010). Companies should aspire to be in the Balanced Resilience Zone (Figure 6).

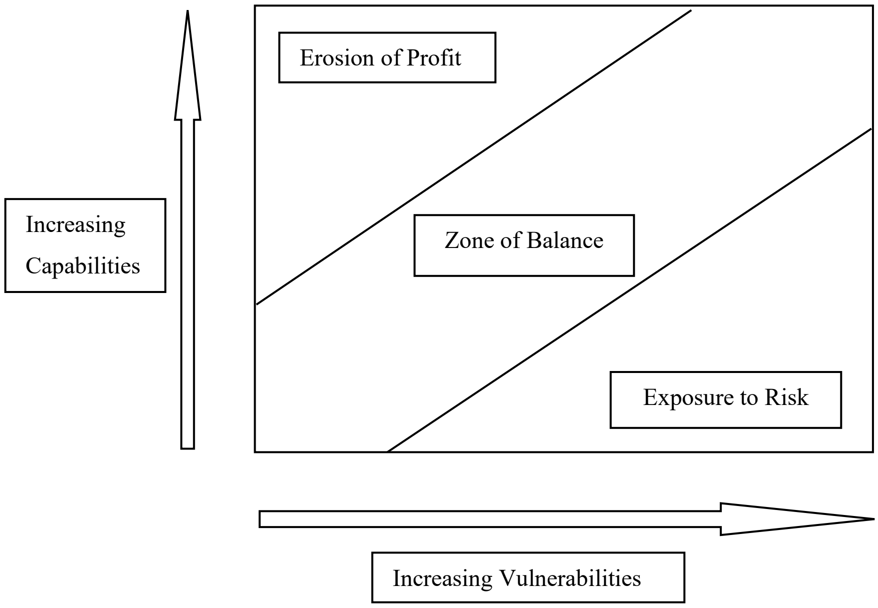

Figure 6. Resilience fitness space (modified from Pettit et al. 2010)

Lacking adequate capabilities in light of the firm's vulnerabilities exposes it to risks but investing in capabilities that aren't needed may erode income. Managing threats is essential but mitigating supply-chain risks without eroding earnings is probably the most difficult task businesses face (Chopra and Sodhi 2004). Centered on the fact that prevention and preparation activities are not free, Tomlin (2006) develops a framework for implementing an optimal disturbance management plan under various degrees of versatility. The risk and capacity constructs were expanded by Pettit et al. (2010) to incorporate 21 variables with 111 subfactors. They suggested that a supply chain's existing state of resilience should be assessed using these 21 factors, and guidelines for resilience enhancements are prioritized by changing their portfolio of capabilities to meet the trend of vulnerabilities to stay in the Zone of Balanced Resilience. The solutions to a threat are diverse, encompassing the capabilities of the whole organization as well as the overlapping or synergistic capabilities of supply chain participants (Hamel and Välikangas 2003; Hendricks et al. 2008; IOMA 2008; Blackhurst et al. 2011). Managers aim to build a portfolio of capabilities that can offset the supply chain's inherent vulnerabilities, culminating in integrated resilience, which is thought to boost firm efficiency. The study's objectives were to first provide a valuable method for assessing the current state of a supply chain's resilience, then establish connections between vulnerabilities and capabilities to achieve balanced resilience, and finally investigate the connection between resilience and efficiency.

To begin, a method was developed to evaluate each component of the Supply Chain Resilience Framework in different firms. Second, a set of focus groups for each involved firm were performed utilizing a multiple case study approach to analyze the recent disturbances to verify the appraisal tool. These focus groups aimed to collect a wide base of knowledge on complex problems rather than to facilitate unity or decision-making (Morgan 1996). This allowed for a thorough examination of the assessment instrument and its capacity to reliably quantify the build of resilience.

A survey-based measurement instrument, the Supply Chain Resilience Assessment, and Management (SCRAM) was designed to subjectively quantify each factor and subfactor dependent on the Supply Chain Resilience Framework (Pettit et al. 2010). Due to the broad extent of supply chain resilience, using several products per subfactor was not feasible to keep the survey within a fair duration (Dillman 2000). The survey ends with questions ranking the relative significance of the variables to assess internal preferences and compare findings between heterogeneous firms (Lambert 2006). The 5-point Likert scale "Agree/Disagree" was used to create ordinal survey answers. Each question and answer is worded in a parallel manner to aid participants in answering rapidly and accurately.

After the data is taken, the capability scare, vulnerability score, and resilience score are there to show the current status of the resilience zone. Knowing the position in terms of resilience is just the first step; to achieve corporate survival and long-term growth objectives, managers need to know how to improve their resilience. The Supply Chain Resilience Framework considers vulnerabilities to be basic parts of the supply chain environment, and they are addressed as soon as possible. Managers must be able to see links between their vulnerabilities and the capabilities over which they have direct control. If management considers Connectivity to be a major weakness, he must first answer the following two questions: What capabilities exist to successfully protect the firm against this threat? And ii) what is the portfolio of capabilities that will best protect against disruptions? Because the goal is to develop and maintain a state of balanced resilience that reduces risks while avoiding investing in over capabilities. (Pettit et al. 2010)

2.8 Summary of the literature review results

In the literature review, Supply chain resilience and risk management were defined more thoroughly. For defining resilience first the supply chain and the metrics were defined which are key points to improve resilience. Metrics are categorized into two parts, one is supply chain metrics and the other one is logistics metrics. These metrics show how the supply chain is working out. So, anything we do to improve resilience will be shown through these KPIs.

Then it was shown how supply chain risk management and resilience are defined in previous works of literature. Supply chain resilience is shown different from traditional risk management, which was the first research question. SC Resilience is described as the capacity to withstand a crisis and to plan ahead of time for a quick recovery in the event of an interruption or change in circumstances. It also includes the capacity to adjust and create adaption to a new balancing state after a crisis, as well as the capacity to anticipate possible issues, monitor, and learn from past crises (Merriam-Webster 2007, Folke et al. 2004).

There are many strategies a firm can follow to gain resilience fit. It is not important that every firm has to follow the same strategies. It depends on the firm and firm's business strategy, depending on what a firm can decide which resilience strategy it can follow. The strategies can be taken both proactively and reactively. These strategies answer research question 2.

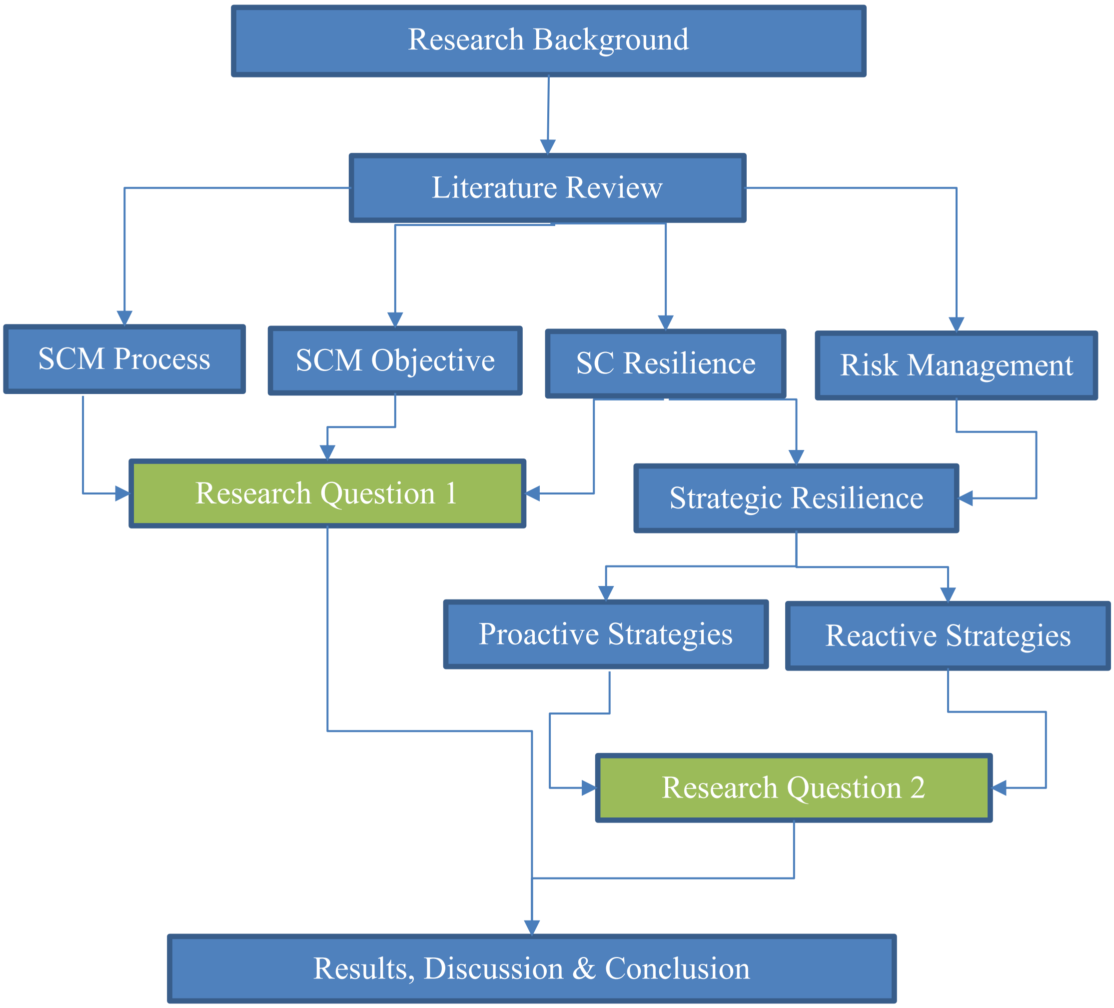

Figure 7: Research Summary

When it comes to reducing risks and guaranteeing continuity, proactive, long-term planning is essential. Proactive strategies of the whole supply chain should be taken into account for every key supplier. The proactive strategies are mainly as follows:

1. Digital technology: IoT, digital twins, blockchain technology are the recent technological advancement in the supply chain. Business continuity is assisted by visibility and understanding of the business process. The value chain of suppliers must be well understood, and systems are required for visibility. Despite the procurement analytics will continue to improve, significant advancements in

analytics are hampered by data quality and consistency difficulties. Introducing AI might result in much more improved resilience (Hofmann et al., 2019).

2. Automation: An autonomous robot can now do stock-taking utilizing RFID for item-level identification more efficiently and consistently than humans using RFID handheld readers. Automation of inter-organizational procedures helps self-steering supply networks. Businesses are under pressure to change their methods and discover new methods to save money as a result of cost pressure. So, businesses must plan carefully to employ automation to boost resilience (Morenza-Cinos et al. 2019).
3. Risk management integration: To ensure systematization in risk management and measures, proactive management is necessary. The most important thing in risk management is the recovery process. To accept changes in suppliers, a firm must first understand the supply network. Integrated supply chain risk management, ISCRM is a collaborative effort between major supply chain firms for ensuring that integration. The main objectives of ISCRM are collaboration, teamwork, and cooperation (Zhu et al., 2017).
4. Human intelligence: Managers must maintain an eye on critical points in the chain. Humans have limited talents in comparison to the huge quantity of intellect accessible today. Much supply-chain intelligence must be automated but there is still a certain need for human engagement. Though the deployment of global agents would surely assist to reduce interruptions, further study is needed to solve other concerns that need human judgment (Blackhurst et al., 2005).

Also, there should be reactive strategies as we can’t foresee every disruption. So, we need to have reactive strategies so that the flow goes back to normal as early as possible without affecting the system too much. Reactive strategies are as follows:

1. Collaboration: Collaboration throughout the whole network may mitigate disruptions. To understand the demands and material or information flow, collaboration with internal stakeholders is crucial. Collaboration is required across SC, as well as with other firms on occasion. The risks can be reduced by developing a collaborative relationship with suppliers and engaging in continuous brainstorming with them. To foresee future hazards, proactive and ongoing supplier monitoring is required, including evaluations, development initiatives, and active supplier management (Zhu et al., 2017).

2. Big data analysis: As statistical models get broader, data accuracy becomes more critical. Big Data Analytics will enhance decision-making and operational performance by extracting meaningful data for three sorts of analytic concerns; descriptive analytics, predictive analytics, and prescriptive analytics, Descriptive analytics uses market intelligence tools to provide daily reports, ad hoc reports, and alerts to get insight into the current state of a company scenario. The goal of predictive analytics is to provide foresight and peeks into the future. Prescriptive analytics improves process models based on predictive analytic models' performance information (Belhadi et al., 2019).
3. Business continuity plan: It is necessary to demand a Business Continuity Plan from vendors. BCP deals with risk recognition through SC, risk assessment, risk analysis with risk probabilities, mitigation strategies, and impacts analysis. Management models, defining roles, employee training, and simulations with suppliers are also included in the BCP (Zsidisin et al., 2005).
4. Inventory management: To mitigate the negative impact of supply chain disruptions, companies use risk mitigation inventory (RMI) and reserve resources to build supply chain flexibility. In the event of a supply chain disruption, RMI is excess inventory that is meant to meet customer demand. It's not the same as holding an operational safety stock to cope with demand fluctuations. There are fixed expenses for conserving the reserve capability, as well as emergency processing expenses incurred when the capacity is deployed and stocking out charge (Lücker et al., 2019).

Two more things were included in the literature review which is the Intertwined Supply Network (ISN) and SCRAM tool. These two are important to maintain the firm to its resilience fit level. The ISN helps the firms' resilience to survive long term and SCRAM helps to assess the system.

3 DISCUSSION

3.1 Key Findings

Supply chain resilience is a comparatively new topic for the industries. The most significant aspect of the resilience idea is that it employs methods that do not require precise quantification (Pettit et al., 2013). One of the key findings of this research is continuous improvement. This involves also monitoring and adapting from time to time. All the strategies are needed to be re-evaluated and adjust periodically. For example, digital technology needs technological up-gradation, the same goes for automation. For collaboration, new stakeholders can emerge, or old stakeholders can be replaced. To adjust to the changes, the strategies need to be updated, even new strategies may need to be applied as well sometimes. Big data analysis and inventory management both are related to real-time metrics and tend to be changed very quickly, so does the strategic move. Even the SCRAM tool needs to be updated and assessed periodically according to the authors (Pettit et al., 2013). It shows the condition of the strategic fit of the current situation which is very likely to change. Change preparedness, visibility, and engagement with partners should be supported by organizational culture. We can summarize the findings from the strategies mentioned by Belhadi (2019) in table 3.

Table 3. Key findings from the research.

Category	Strategies	Benefits	Stakeholders
Proactive Strategies	Digital Technology	• Improved supply chain durability. • Better procurement analytics. • More inductive analysis methods. • Real-world uncertainty prediction.	SC team, IT team, Top management.
	Automation	• Improved effectiveness and reliability on the process level. • Better inventory control. • Reduced dependencies and uncertainties.	SC team, Employees related to the process, IT, Inventory managers.
	Risk Management Integration	• Foresee and tackle uncertainties. • Long-term longevity and profitability. • Ensure firm's continuity and viability. • Maintain cash flow, return on expenditure, and gross margin on sales. • Increased market share and income.	Stakeholders related to the firm; suppliers, logistics team, SC team, inventory.
	Human Intelligence	• Monitor and control the checkpoints. • Better decision through analysis and judgment. • Reduce risk considering more variables.	Managers, Top management.

Reactive Strategies	Collaboration	• Loss minimization from disruptions. • Better operational output. • Decrease supply risk.	Suppliers, Operation managers, top management, logistics.
	Big Data Analysis	• Provide effective support to timely decision-making. • Increase operational performance by extracting meaningful data. • Gain insight into the actual condition of a business situation. • Reveal the root causes of an issue. • Foresights and glimpses into the future. • Optimizes process models.	SC team, IT, managers, top management.
	Business Continuity Plan	• Recovery and also prevention from potential disruptions. • Rebound from a crisis that disrupts operations. • Lower the risk and/or severity of supply chain disturbances.	Top management, Operational managers.
	Inventory Management	• Create supply chain flexibility. • Satisfy consumer demand in the case of a supply chain interruption. • Minimizing disturbance danger under deterministic demand.	Inventory team, SC team, logistics.

Table 3 shows how these strategies are beneficial for the supply chain. A strategy can sometimes work as both proactive and reactive. For example, Collaboration works reactively after a disruption to mitigate disruption impact; but also, it can work proactively to withstand future potential disruptions. As they are related to the supply chain, in all the strategy mainly includes the supply chain team as key players. IT and top management also play vital roles in these strategies. Sometimes suppliers and other stakeholder firms can be also crucial for establishing a strategy for better resilience fit.

3.2 Critical Evaluation

This research was mainly based on a literature review. An empirical study could have been much conclusive. The SCRAM assessment tool needs data from firms, connecting scram with strategies would have been more interesting. Any case study regarding these strategies would have added more value to the research. Also defining which strategy works on which KPI would have given a clearer picture of the outcome of those strategies. Many good and recent references were used in this research which can make it reliable. The authors from the references that were taken are very well known in the field of supply chain literature. There are many recent articles available in this field of research. There was not much research done earlier but past few years there is much research done by renowned authors like Ivanov (2013), Dolgui (2020), Pettit (2010, 2013), Belhadi (2019, 2021), etc. The result of this research is a kind of extension of Belhadi's (2019) paper on Manufacturing and service supply chain resilience to the COVID-19 outbreak where he also categorized the strategies into proactive and reactive strategies.

3.3 Topics for Future Research

In this research, eight different strategies for improving resilience were discussed. Many other strategies were not covered in this research. More research can be done in different sectors of business and more strategies can be found. For example, suppliers' strategies would have been different from a manufacturer, also an automobile firm's strategies are different from the food industry. An empirical study with more data can be done in the future for SCRAM. Involving AI in digitalization or decision-making could be a very interesting research topic for future research.

4 CONCLUSIONS

As the world is changing very fast with Industry 4.0, additionally recent global pandemic affects supply chain networks and they are becoming more susceptible to threats and delays. This research provides knowledge about supply chain resilience and reviews how SCRES strategies are described in the literature and managed in firms. It is focusing on risk management, resilience, and resilience strategies. Two research questions were answered in this research:

RQ1: How are supply chain resilience and risk management defined in the literature?

Supply chain resilience's definition and the difference between risk management and SCRES are described in the research. The ability to endure a crisis and prepare ahead of time for fast recovery in the case of an interruption or change in circumstances is referred to as supply chain resilience. It also encompasses the ability to modify and adapt to a new balanced condition after a crisis, as well as the ability to predict potential problems, monitor, and learn from previous crises. So, unlike risk management, supply chain resilience does not aim for returning to its original shape following a disruption, but it aims to adapt into a new configuration that can prevent the disruption or prevent loss from the disruption. It does not require a comprehensive list of potential outcomes or assumptions for a descriptive future, like traditional risk management.

RQ2: What strategies and methods are available for improving supply chain resilience?

The strategies were categorized into two categories: proactive and reactive strategies. Proactive strategies included Digital technology, Automation, Risk management integration, Human Intelligence, and the Reactive strategies included Collaboration, Big data analysis, Business continuity plan, and Inventory management.

For future research more strategies can be included, and also empirical studies can give a more informative view of the results. SCRES building requires clear requirements and specifications defined in internal collaboration. More proactivity, planning, and internal and external collaboration are needed in risk preparedness and business continuity management. Systematic and proactive SRM is essential in SCRES capabilities management and improvement through whole SC to ensure uniform SCRES.

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