

The Impact of Digital Technologies on Supply Chain Resilience: A Framework Analysis

Xiaopu Zhang^{1,a,*}

¹*University of Southern California, Marshall School of Business, Los Angeles, 90007, United States*
a. xiaopuzh@marshall.usc.edu

**corresponding author*

Abstract: In the context of global disruptions, such as the COVID-19 and geopolitical shifts, the significance of supply chain resilience (SCRES) has grown. These disruptions have highlighted the need for more resilient, flexible, and adaptable supply chains that can respond to unexpected emergencies. This paper examines the role of digital technologies in enhancing SCRES through a framework that integrates digitalization with supply chain performance. By synthesizing existing literature and utilizing a framework analysis, the study evaluates key indicators that influence various resilience dimensions. It further clarifies the intricate relationship between digitalization, SCRES, and performance outcomes. A case study of 3M's digital revolution highlights the importance of digital tools in improving supply chain practice during disruptions. The findings of this study highlight that digital technologies are not only pivotal for enhancing SCRES but are also crucial for building a resilient supply chain capable of mitigating future uncertainties and optimizing performance across the entire supply chain network.

Keywords: Supply chain management, Resilience, Performance, Digital technologies.

1. Introduction

The significance of SCRES has increased due to the ongoing effects of the epidemic and notable shifts in the geopolitical landscape. In recent years, scholars have proposed various approaches to this issue. One stream of scholars focuses on model construction, aiming to develop or validate supply chain models with greater resilience. For instance, Jain et al. presented a hierarchical SCRES model, while Soni et al. quantified resilience through graph theory models [1][2]. Another stream of scholars combines experiments or practical applications with theoretical frameworks to develop measurement tools or identify influencing factors to enhance SCRES. For example, Pettit et al. identified key links that improve SCRES by examining data from global manufacturing and service companies and demonstrated that these links can enhance overall performance [3]. Additionally, some scholars have summarized the definition and development of SCRES through literature reviews, such as Tukamuhabwa et al. However, existing research lacks specific analyses of supply chain management in typical enterprises, particularly case studies that adapt to the current social context. This paper will focus on 3M, analyzing its strategies for optimizing the supply chain in a digital environment and providing insights for similar companies.

2. Digital Technologies in SCRES

2.1. Definition and Development of SCRES

The notion of SCRES is interdisciplinary and encompasses several domains [4][5]. Previous literature usually defines SCRES in terms of a variety of characteristics, with the most classic being described and elaborated from a capacity standpoint [2][3]. Ponis and Koronis provide the most comprehensive and widely cited definition, which defines SCRES as being capable of actively plan and structure the supply chain to prepare for unplanned disruptions, as well as the capacity to respond to these disruptions in a way that protects the supply chain's framework and function [4]. The goal is to recover and achieve a more robust operational state, possibly improving on the pre-disruption situation, thereby gaining a competitive advantage [6].

There are four main research approaches in academic research on SCRES, with the largest number of studies focusing on SCRES concept definition and theoretical summarization, followed by constructing models, which are also popular research approaches, and a relatively small number of case studies and survey studies [4]. In literature reviews, theoretical advancements and associated resilience indicators are primarily summarized. For example, Tukamuhabwa et al.'s three-phase literature search and screening process resulted in a thorough definition and strategy overview of SCRES utilizing 91 articles/sources [4]. Another popular study strategy is model creation. Examples of this include the hierarchy-based SCRES model created by Jain et al. and the quantitative model of SCRES index developed by Soni et al. using graph theoretic modeling [1][2].

2.2. Digitalization in SCRES

2.2.1. Indicators for SCRES

The success of SCRES depends on its capacity to react quickly to unforeseen or disruptive situations [7]. A resilient network must be capable of both anticipating potential crises and managing current disruptions. In the case that an unforeseen event causes a disruption, it should also be capable of quickly recovering and returning to its initial state [6]. Supply chain crises are typically divided into three phases: pre-crisis, when the disruption has not yet occurred; crisis, when the supply chain is actively dealing with the disruption; and post-crisis, which involves the recovery process following the disruption. Each phase demands specific capabilities. In the pre-crisis phase, absorptive capacity is key. This includes network redundancy and the ability to perceive and visualize potential risks. During the crisis, responsive capacity becomes critical, requiring the ability to quickly react and manage the disruption. Post-crisis, the focus shifts to restorative capacity, which implies the capability to restore the supply chain to its pre-crisis state efficiently and cost-effectively [5].

Additionally, robustness is a crucial aspect of SCRES. The capacity of a supply chain to tolerate changes is referred to as robustness, whether by proactively seeking adjustments before sudden changes occur or by resisting unfavorable outcomes during the change process [4][7]. In this paper, robustness is also attributed as a component of SCRES dimensions within the scope of absorptive capacity. Therefore, based on the various stages of crisis response, resilience indicators can be categorized into the three aforementioned dimensions. These key indicators, which are listed in Table 1, are capable of being used to evaluate the supply chain's resilience in each dimension.

Table 1: Indicators for supply chain resilience.

Capability	Indicators	Definition	Authors' Name
Absorptive capability	Flexibility	The capacity of a supply network to quickly adapt to the demands of its partners as well as the surrounding environment	Singh et al. (2019)
	Visibility/Transparency	The capacity of individuals involved in a supply chain to observe both ends and identify any interruptions	Singh et al. (2019)
	Redundancy	It entails making important and crucial use of additional stock that could potentially be used to handle issues in an emergency.	Singh et al. (2019)
	Robustness	The capacity of a supply network to resist change, including proactively seeking change before it occurs or resisting adverse reactions during change	Singh et al. (2019), Tukamuhabwa et al. (2015)
Response capability	Agility	The capacity to swiftly adapt to unforeseen shifts in markets and the natural environment	Singh et al. (2019), Tukamuhabwa et al. (2015)
Recovery capability	Adaptability	The capacity to accept change as inevitable and design a framework that can adapt to changing circumstances and goals	Jain et al. (2017), Singh et al. (2019)
	Sustainability	The capacity to use resources to address current issues rather than relying on those meant for solving future personal problems	Singh et al. (2019), Zhao et al. (2023)

2.2.2. Theoretical Structure

With the growing prevalence of digital technologies, along with the impact of geopolitical factors and COVID-19, the digitization of supply chains has emerged as a significant trend. Since 2022, digital technologies such as Artificial Intelligence (AI) and Machine Learning (ML) have gained increased attention, further driving the research and development of digitized supply chains [5][8]. In order to establish a system that prioritizes data-driven decision-making, supply chain digitalization (SCD) entails incorporating technological innovations like Big Data, Blockchain, cloud services, the Internet of Things (IoT), and AI/ML into supply chain operations [5][8][9].

In this paper, we adopt the analytical framework of "Supply Chain Digitalization (SCD) → Supply Chain Resilience (SCRES) → Supply Chain Performance (SCP)" to connect SCRES with digitalization [5]. Furthermore, by incorporating the SCRES indicators from Table 1, the relationship between SCD, SCRES, the indicators, and SCP is outlined in Table 2.

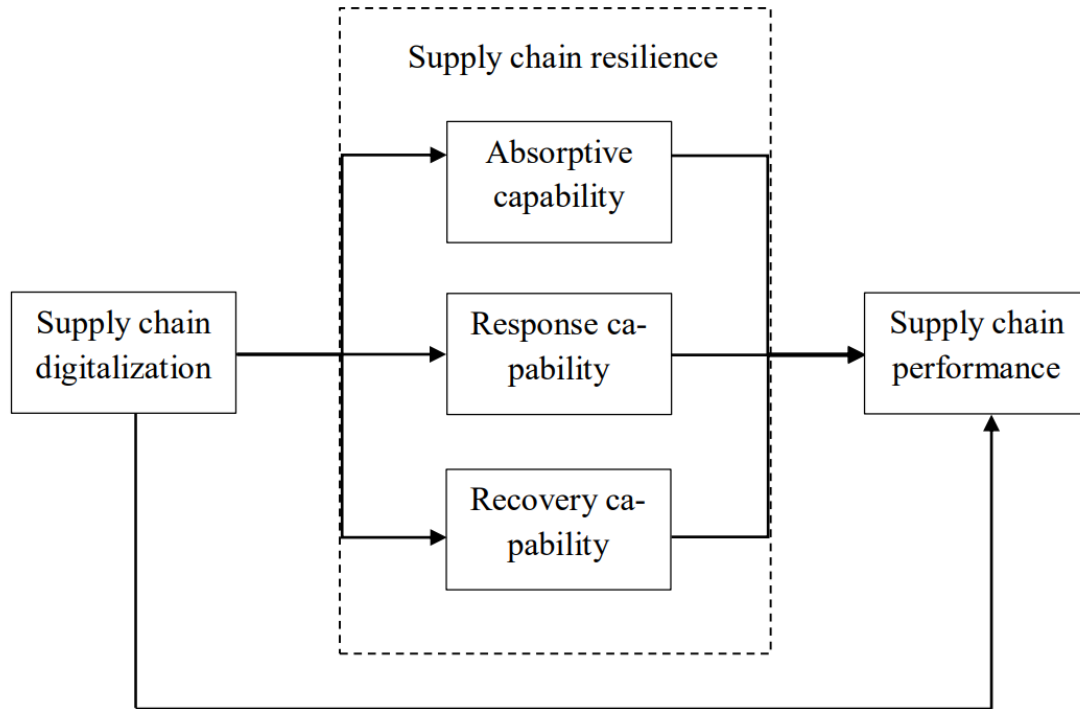


Figure 1: Research model of SCR and SCD.

Table 2: Constructs and indicators.

Construct	SCRES capabilities	Indicators	SCP
SCD1	Absorptive	Flexibility	SCP1
		Visibility/Transparency	
		Redundancy	
		Robustness	
SCD2	Response	Agility	SCP2
SCD3	Recovery	Adaptability	SCP3
		Sustainability	

2.2.3. Analysis of SCD, SCRES, and SCP Relationship

Zhao et al. concluded that the establishment of SCD not only directly impacts SCP but also enhances a supply chain's risk response and adaptability by improving its coping mechanisms and resilience, ultimately leading to stronger SCP improvements [5]. SCD positively influences absorptive capacity by enabling the network to absorb and mitigate the negative effects of disruptions. This enhances supply chain transparency and allows partners to share information more effectively. Additionally, key digital technologies like AI/ML can be used to predict and analyze risks within the network, minimizing the impact of disruptions.

SCD also strengthens responsiveness and resistance by enabling quick reactions to disruptions. For example, AI and big data analytics accelerate decision-making, while cloud platforms ensure real-time communication across the network, allowing for swift responses to crises or necessary adjustments. Cloud computing further improves the accuracy and timeliness of risk response by making decision-making more objective.

Moreover, SCD also improves a supply chain's capacity to bounce back from interruptions faster and more effectively. The integration of digital tools improves coordination, resource reallocation, and network management after a disruption. Digital collaboration among supply chain partners facilitates recovery and upgrading, while data sharing and information exchange promote innovation in future supply chain operations.

3. Case Analysis of 3M

3.1. Case Overview

Founded in 1902, 3M is known for its innovative approach to product development, which ranges from common consumer products such as Post-It notes to specialized industrial materials and medical supplies. Yet 3M faces significant challenges beginning in 2019, starting with lower-than-expected earnings and further impacted by the COVID-19 pandemic. The pandemic led to a 400% surge in demand for medical products such as N95 masks, causing supply chain disruptions and production struggles [10]. Despite its digital transformation efforts, 3M continued to face labor shortages, raw material delays and increased operating costs, while dealing with a tense geopolitical situation and ongoing supply chain disruptions. According to Zhang and Gu, SCD has a more significant driving effect on companies with high environmental uncertainty, low internal control level, or at the downstream of the industrial chain [8]. Therefore, in order to cope with the uncertainty of the external environment and improve the resilience of the supply chain, 3M has also taken digital measures to cope with it.

3.2. Digital Transformation Analysis

3.2.1. Adoption of Digital Technologies

3M's digital transformation started before the pandemic, with a significant reform of its digital operating system implemented a year earlier [10]. This reform overhauled the company's enterprise resource planning (ERP) system, connecting 3M's factories, suppliers, and other supply chain participants globally. The updated ERP allowed seamless, low-cost communication across the supply chain and enabled integration, capacity planning, network optimization, and information sharing within a single system. A key aspect of this transformation was 3M's partnership with Amazon Web Services (AWS). As a multinational enterprise (MNE), 3M generates vast amounts of data daily. Its aging internal data centers posed risks in handling this information, prompting the migration of thousands of applications to AWS. This shift provided 3M with scalability, flexibility, and innovation capabilities that traditional data centers could not offer.

Beyond operational digitalization, 3M also transformed its business model, notably achieving a breakthrough in e-commerce in 2023. Partnering with Mirakl, 3M developed a B2B e-commerce platform. Mirakl's marketplace model helps 3M reduce inventory backlogs, improve agility, and increase profitability. The digitization of business models enables better data collection, enhances understanding of customer needs, and improves communication efficiency. It also strengthens relationships between companies and distributors, allowing timely communication of vital information like inventory availability and transportation capacity through digital channels.

3.2.2. Effects on SCRES and SCP

The digitalization of operations and business models has established closer ties between 3M and its suppliers, which allows potential crises to be better predicted and prevented. Improved supply chain visibility and decision-making capabilities are key to 3M's ability to respond quickly to the surge in demand during Covid-19. The supply chain's ability to respond to crises is mainly reflected in its agility, that is, the ability to quickly identify problems, find solutions, and implement solutions to solve problems. In the early days of the epidemic, facing the market's surging demand for medical supplies, especially masks, 3M's enhanced ERP system and the spare capacity prepared in advance made it possible to quickly digest some of the surging demand, which was the key to solving the problem. One sign of the improved general resilience of the 3M supply network is the improved sustainability of the company's supply chain operations, which has been greatly aided by digital operations, particularly cloud services. For example, by working with paper suppliers to track the trees where products come from, 3M is able to implement information flows between digital partners to implement sustainable procurement. Cloud-based applications provide 3M with the possibility to implement more sustainable supply chain practices and advocate responsible procurement and traceability.

Several significant areas show how digitalization has affected 3M's SCP. First, the B2B platform has fostered positive interactions between 3M and its customers, significantly enhancing customer satisfaction. In the past, customers often had to click the "Where to Buy" button about 20 times to find the products they needed. The introduction of the 3M marketplace has simplified the process, making it much easier for them to locate products and significantly saving their time. This improvement in users' experience has also led to a sixfold increase in the revenue of 3M's partners [11]. Additionally, 3M can now utilize platform data to further enhance customer experience in a more targeted manner. Secondly, the updated ERP and cloud service platforms have greatly reduced the communication costs of all participants on the supply chain. At the same time, the improvement in demand forecast accuracy, timely problem detection, and shorter delivery cycles have reduced the company's production costs while boosting efficiency. Lastly, digital operations and business models have facilitated 3M to expand its brand influence. Lastly, digital operations and business models have provided 3M with opportunities to expand its brand influence. Despite having a good reputation in both the consumer goods and industrial production sectors, 3M has faced increasing competition from lower-priced alternatives in recent years. As a result, leveraging digital technology to boost marketing efforts and increase consumer favorability has become an essential strategy for 3M moving forward.

3M struggles with prioritizing and strategies even if it understands the great possibilities of digital technologies for SCD. Despite investing in digitization and expanding their supplier pool, they faced difficulties in optimizing technologies for maximum impact and future resilience. In addition to strengthening their cloud partnership with Amazon and updating their ERP system, 3M began experimenting with AI/ML, blockchain, and IoT technologies to improve risk alerts, enhance customer experience, and bolster digital security. However, the wide range of initiatives made prioritization challenging, and the numerous investments diluted the impact of any single technology. Moreover, declining revenue and competition from peers still seem to be its biggest challenges.

4. Conclusion

This study underscores the pivotal role of digital technologies in reinforcing SCRES, particularly in crisis management. The integration of AI/ML, IoT, cloud computing technologies and Ecommerce has proven effective in enhancing supply chain visibility, facing unforeseen supply chain challenges, accelerating decision-making processes, and improving recovery speed. The case analysis of 3M indicates that although there has been a great deal of progress in the adoption of these technologies,

there are still issues with optimizing their use to maximum impact on SCRES. The findings suggest that a more strategic approach to the implementation of digital tools is essential to fully leverage their potential in enhancing both resilience and performance. These insights contribute to the ongoing discourse on SCRES and offer practical implications for organizations seeking to develop more adaptive and robust supply chains in the face of future disruptions. However, this paper is mainly depend on one single case study, which may not fully represent the range of digital transformation methodologies employed across different industries. Future research could examine and investigate the impact of digital technology on SCRES and SCP from a broader viewpoint, combining cases from various domains.

References

- [1] Jain, V., Kumar, S., Soni, U., & Chandra, C. (2017). Supply chain resilience: model development and empirical analysis. *International Journal of Production Research*, 55(22), 6779–6800. <https://doi.org/10.1080/00207543.2017.1349947>
- [2] Soni, U., Jain, V., & Kumar, S. (2014). Measuring supply chain resilience using a deterministic modeling approach. *Computers & Industrial Engineering*, 74, 11-25.
- [3] Pettit, T. J., Croxton, K. L., & Fiksel, J. (2013). Ensuring supply chain resilience: development and implementation of an assessment tool. *Journal of business logistics*, 34(1), 46-76.
- [4] Tukamuhabwa, B. R., Stevenson, M., Busby, J., & Zorzini, M. (2015). Supply chain resilience: definition, review and theoretical foundations for further study. *International Journal of Production Research*, 53(18), 5592–5623. <https://doi.org/10.1080/00207543.2015.1037934>
- [5] Zhao, N., Hong, J., & Lau, K. H. (2023). Impact of supply chain digitization on supply chain resilience and performance: A multi-mediation model. *International Journal of Production Economics*, 259, 108817.
- [6] Ponis, S. T., & Koronis, E. (2012). Supply Chain Resilience? Definition of concept and its formative elements. *The journal of applied business research*, 28(5), 921-935.
- [7] Singh, C. S., Soni, G., & Badhotiya, G. K. (2019). Performance indicators for supply chain resilience: review and conceptual framework. *Journal of Industrial Engineering International*, 15(Suppl 1), 105-117.
- [8] Zhang Shushan, Gu Cheng. Enterprise Digital Transformation and Supply Chain Resilience[J]. *South China Journal of Economics*. 2024(08):137-158.DOI:10.19592/j.cnki.scje.412230.
- [9] Bigliardi, B., Filippelli, S., Petroni, A., & Tagliente, L. (2022). The digitalization of supply chain: a review. *Procedia Computer Science*, 200, 1806-1815.
- [10] MILLER, S. M., & BHATTACHARYA, L. (2022). 3M: Rethinking regionalisation to adapt to supply chain disruptions.
- [11] Matasci, S. (2023). How 3M is using its marketplace to win in B2B eCommerce. Mirakl. <https://www.mirakl.com/blog/how-3m-is-using-a-b2b-marketplace-to-power-digital-transformation>