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COMMENTS

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Disruptive technologies for advancing supply chain resilience

Abstract Disruptive technologies provide a new paradigm for supply chain risk management and bring opportunities and challenges for the improvement of supply chain resilience (SCRes). This study summarizes the application cases of some disruptive technologies in the SCRes and analyzes the benefits and damages brought by disruptive technologies to the SCRes. The results show that disruptive technologies can provide the supply chain with flexibility, visibility, agility, and other capabilities at various stages of risk management. Hence, technology advancements greatly increase the level of the SCRes. Although disruptive technologies undermine the construction of SCRes, these damages can be eliminated through technology iteration or other disruptive technologies. Furthermore, disruptive technologies will provide better stability for the SCRes. The study also makes several suggestions for the use of disruptive technologies in the construction of the SCRes.

Keywords supply chain resilience, disruptive technology, supply chain risk

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1 Supply chain resilience: Concept and significance

Supply chain risk is a key topic in operation management that has gained widespread attention over the past two decades. Supply chains involve business, logistics, and information flow. Moreover, they include production, transportation, storage, information processing, and many other processes. Problems in any of the processes will affect supply chain security and cause supply chain risks. In the studies of supply chain risks, the risks can be divided into operational risks (e.g., risks of demand fluctuations and delivery delays) and disruption risks (e.g., supply chain disruptions due to COVID-19), or internal risks (e.g., risks in the procurement, delivery, and manufacturing) and external risks (e.g., risks from macroeconomic and policy uncertainty) (El Baz and Ruel, 2021; Um and Han, 2021; Ning et al., 2023). Scholars have proposed many analytical models and measures to explore how to capture supply chain risks and mitigate their impacts (Ho et al., 2015; Wei et al., 2023). In particular, improving the resilience of supply chain is a topical issue in coping with supply chain risk.

The concept of supply chain resilience (SCRes) was proposed by Rice Jr and Caniato (2003). Christopher and Peck (2004) summarized the definition of SCRes as "the ability of a system to return to its original state or move to a new more desirable state after being disturbed". Subsequently, research conducted was focused on the ability of SCRes to prepare for and respond to risks. At present, SCRes is commonly defined as the adaptive ability of supply chains to prepare in advance for potential emergencies, respond quickly after disruptions, and recover from them (Gao et al., 2021). Adaptability, response, recovery time, and control are important characteristics of the SCRes (Ponis and Koronis, 2012). Scholars have found that some technologies not only help supply chains possess important characteristics but also increase sales volume, market share, and customer satisfaction in companies (Ivanov et al., 2017; Fakhimi and Miremadi, 2022). Therefore, scholars are constantly improving companies' SCRes through technology.

With the evolution of industrial automation, digitalization, and intelligence, new technologies have influenced the paradigm of supply chain management. These disruptive technologies represent major advancements in technology. They can achieve dramatic changes in the price/performance ratio and even change the behavioral patterns of users (Roland Ortt et al., 2007). In the study of the SCRes, blockchain, Internet of Things (IoT), and artificial intelligence (AI) are essential disruptive technologies (Ivanov et al., 2019; Misra et al., 2022). These technologies make supply chains resilient. For example, additive manufacturing technology reduces the risk of delivery delays and enhances the flexibility of supply chains (Khajavi et al., 2014). Meanwhile, blockchain solves the trust risk between companies and improves the transparency of the supply chain (Babich and Hilary, 2019). Compared with traditional methods, such as adding redundancy and contingency, disruptive technologies are more efficient and have advantages in improving SCRes. Although disruptive technologies do not solve all the problems arising from supply chain risks, they have great potential to improve SCRes.

2 Typical disruptive technologies for enhancing supply chain resilience

According to the development needs of the digital age, IoT is the key technology for digital transmission. In addition, blockchain is the key technology to ensure the authenticity of digital information. Meanwhile, AI is the key technology to improve the data intelligence service. These three disruptive technologies support the digital production architecture. As shown in Table 1, they have many practical applications for improving SCRes in a variety of industries around the world. Next, we will focus on how the three technologies can be applied to solve supply chain risks.

First, AI is the most important of the three technologies in addressing supply chain risk. It refers to "the science of making machines do things that would require intelligence if done by men" (Pournader et al., 2021). It mainly has two features. First, it imitates human thinking and helps humans make optimal decisions. Second, it imitates human behavior and accomplishes tasks for humans (Baryannis et al., 2019). In terms of imitating human thinking, big data analysis technology is widely used in supply chain risk forecasting and decision analysis, including market change forecasting, management plan optimization, resource overrun alerts, and other functions (Mani et al., 2017; Zhao et al., 2017). Some companies also apply big data technology to improve SCRes. For example, Unilever forecasts future sales volume and demand through big data analysis to avoid stock shortages and excessive stock redundancy (CFLP, 2015). Through big data analysis technology, companies can identify supply risks quickly and make reliable corresponding decisions. In terms of imitating human behavior, robots with AI technology are already widely used to address supply chain risk and resilience issues. For example, with the increase in global tourists, Thai Hotels introduced AI robots to meet the needs of tourists and ensure the stability of the tourism supply chain (Panichayakorn and Jermsittiparsert, 2019). During COVID-19, many logistics companies used automated sorting and distribution robots to solve the problem of logistics disruptions, which improved the flexibility of the supply chain (Shi et al., 2021; 2023; Liu et al., 2022).

Secondly, IoT has a wide range of applications in SCRes. It is defined as a network of entities connected by sensors that enable these entities to be located, identified, and manipulated (Ng and Wakenshaw, 2017). In the study of the SCRes, data interaction is the key function of IoT technology. Data interaction enables people to capture and transmit the information of entities easily and ensures the real-time effectiveness of data collection in the supply chain. Given its significant value, the IoT is gaining attention in academic research and supply chain management practice in industries. In the field of academic research, for example, Theorin et al. (2017)

Table 1 Some cases for disruptive technologies in the SCRes

Technology	Country	Industry	Measure	Reference
IoT	US and South Korea	Machine production	Real-time monitoring of information	Higgins (2015)
	Germany	Car manufacturing	Real-time information capture	Sarac et al. (2010)
	US	Computer software	Distributed computing	Gupta and Jones (2014)
AI	UK and Netherlands	Daily necessities	Market change forecast	CFLP (2015)
	UK	Government agency	Resource overrun alert	Morabito (2015)
	China	Wholesale trade	Intelligent robotic delivery	Yi et al. (2022)
Blockchain	US	Retail	Information tracking and tracing	Kamath (2018)
	US	Agriculture	Historical information remains true and unchanged	Rogerson and Parry (2020)
	China	Shipping	Smart contracts	Verhoeven et al. (2018)

incorporated intelligent manufacturing network technology into the production process of automobile manufacturing. Through sensors and Internet systems, car manufacturers can adjust the sequence of operations according to the actual number of customer orders and capacity to achieve agile responses to risks. Tsang et al. (2018) found that through IoT, such as wireless sensors and cloud databases, companies can monitor product temperature, humidity, light intensity, and even the health status of operators. Any abnormal data can be detected in real time by managers, which improves the visibility of the supply chain. In the field of company practice, IBM and Samsung launched the ADEPT cooperation project (Higgins, 2015). As Paul Brody, the head of IBM said, they can connect the data and devices of companies and organizations around the world through the IoT and share energy and bandwidth during the operation of the network of devices. Any abnormal data in the network can be found in time, thus effectively enhancing the SCRes.

Finally, blockchain technology has significant value for SCRes. It can be defined as distributed database, which contains a list of various records that are linked together in an orderly fashion (Xia et al., 2017). Information immutability, decentralization, openness, transparency, and smart contracts are key features of blockchain technology. In studies on supply chain risk and resilience, the features of blockchain technology are often used to improve trust among supply chain members and reduce supply chain risks caused by fraudulent behaviors, such as tampering and fabrication. For example, Agrawal et al. (2021) proposed a traceability framework based on blockchain and designed operational smart contracts and verification rules. Through smart contracts, the supply chain members will disclose the transaction information, and each member can trace the source of the information, thus making the supply chain transparent and real. Some studies have also found that supply chains using blockchain technology have lower operational risks than traditional supply chains (Choi, 2020). In addition to reducing the supply chain risks caused by tampering and fabrication, blockchain technology has been applied in the study of data loss, transaction risk, and other aspects of the supply chain (Liu et al., 2023). In practice, as early as 2015, the US planned to eliminate loopholes in the logistics supply chain system through blockchain technology. In 2020, IBM, Amazon, Accenture, and other companies submitted a report titled *Potential Uses of Blockchain by the US Department of Defense*. The report attracted the attention of the US Department of Defense, which has begun to use blockchain technology to improve the resilience of its logistics supply chain.

3 Impact of disruptive technologies on supply chain resilience

The SCRes can be measured in three stages: The preparation stage before risk events, the response and recovery stage after risk events, and the growth/competitive advantage stage after risk events (Tukamuhabwa et al., 2015). The role of disruptive technologies in SCRes has been widely discussed at the three stages of risk. In the preparation stage before the risk event, many scholars have carried out exploration. For example, Hollnagel et al. (2006) emphasized that risk identification and forecasting are the key points in the preparation stage. If the deviation of signals can be monitored and the occurrence of disasters can be forecast, the recovery can be prepared in advance. As shown in Fig. 1, in risk identification, IoT technology provides visibility into the supply chain through real-time data collected by sensors. In particular, track and trace technology can locate the exact location of goods and the number of inventory in real time (Chiacchio et al., 2022).

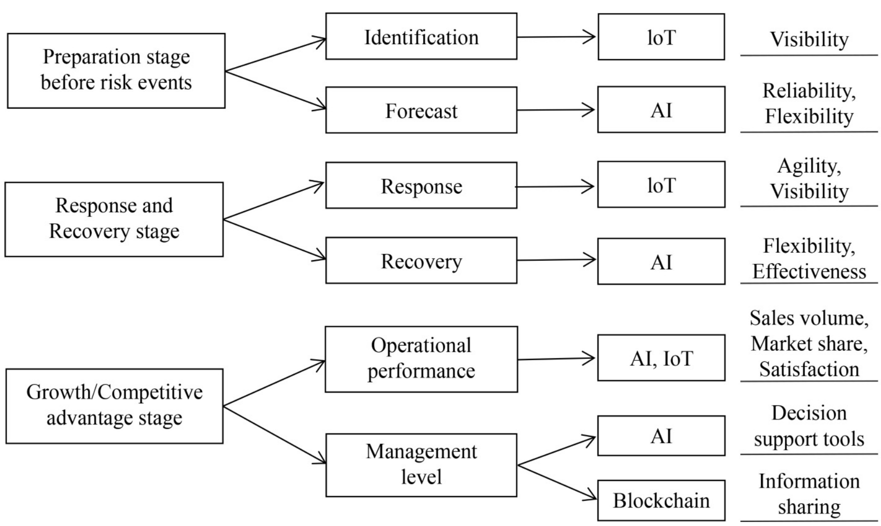

Fig. 1 Characteristics of disruptive technologies in the SCRes.

In this case, the manager and the buyer can monitor whether the goods are moving abnormally at any time. In risk forecasting, AI, as well as big data analysis in particular, can provide forecast results based on effective algorithms and a huge amount of data. On the one hand, machine learning can accurately capture the data characteristics and provide the best choice in the future according to the data characteristics to improve the reliability of the supply chain. This method is more reliable than manual decision-making. On the other hand, through the forecasting of demand, output, and other aspects, companies can understand the complex market in advance and adjust purchases and inventory at any time. This forecasting improves the flexibility of the supply chain.

In the response and recovery stage, companies need to reallocate resources as quickly as possible to recover from supply chain disruptions (Chowdhury and Quaddus, 2016). Therefore, companies urgently need disruptive technologies to provide agility, flexibility, and productivity support. In the risk response stage, the issue is not the lack of information but the lag between data collection and action (Ben-Daya et al., 2019). IoT technology can reduce the time needed to respond to risks by collecting and transmitting data in real time, thus allowing for maximum agility and responsiveness. In addition, some technologies combining IoT and AI are being used to assess and manage supply chain risks. For example, digital twin technology can simulate the operation process of supply chains and identify managers' risk sources and solutions in the shortest time possible (Burgos and Ivanov, 2021). During the risk recovery stage, AI technology improves productivity. Even without human intervention, the whole factory can operate itself. Additive manufacturing technology, for example, not only reduces production costs but also enables on-demand production and reduces inventory costs. Especially in the event of a global supply disruption, the ability to produce on demand with just one drawing greatly increases the flexibility of the supply chain.

Disruptive technologies also play an essential role in the growth/competitive advantage stage. On the one hand, from the operational performance perspective, disruptive technology is an indication of the companies' ability to apply innovation, which can increase sales volume, market share, and customer satisfaction (Fakhimi and Miremadi, 2022). On the other hand, from the perspective of management, disruptive technologies have improved the performance of supply chain management. For example, big data analysis brings decision support tools to managers. In addition, blockchain technology increases the level of information sharing and trust between companies within the supply chain and promotes their connectivity. Disruptive technologies not only play a key role in the three stages of preparation before risk events, response and recovery after risk events, and growth/competitive advantage after risk events, but also contribute to the ability to improve the SCRes.

Although disruptive technologies have improved the SCRes, the use of technologies still has some negative impacts on the SCRes in terms of technological immaturity and managers' overreliance on technologies. On the one hand, technological immaturity may lead to more severe supply chain disruptions. For example, a simple error in a sensor can cause incorrect data to be shared throughout the supply chain. If it happens during a medical procedure, such errors can even cause fatal injuries to patients. Although blockchain technology guarantees transparency and information immutability, proving whether the data are real from the beginning is impossible, which can have serious ripple effects on supply chains (Kim and Shin, 2019). On the other hand, managers' overreliance on technologies may also negatively affect the construction of the SCRes. In particular, technologies tend to reinforce existing power dynamics and social inequalities rather than break them to create equality (Sharma and Joshi, 2020). Specifically, this scenario will lead to data privacy disclosure (Gao et al., 2017), inconsistent data collection methods among supply chain members (Weisenfeld, 2011), a digital divide (Burns and Thatcher, 2015), and other problems. When these problems exist, the construction of the SCRes will become a glass building. Although technologies support the effectiveness of the SCRes, they have inevitable vulnerability.

However, through technology iteration or other disruptive technologies, the negative impact of disruptive technologies on the SCRes can be eliminated. For example, the combination of the IoT and blockchain technology not only guarantees data privacy and security but also solves the problem that blockchain cannot guarantee the reliability of the data. Thus, it provides a complete solution for the construction of the SCRes (Cui et al., 2019; Pavithran et al., 2020; Chen et al., 2023). In the beginning, cloud technology was only used as a tool for distributed computing. After it is combined with big data, IoT, and other technologies, people can purchase all kinds of technologies at the smallest unit to realize various functions, including data mining and utility computing (Fernández et al., 2014). Disruptive technology helps supply chain members allocate resources rationally and realize the SCRes within limited resources. With more other disruptive technologies, the negative effects caused by disruptive technologies are eliminated, and the improvement of the SCRes becomes more stable.

4 Conclusions and insights

4.1 Main conclusions

Disruptive technologies have increased the SCRes and boosted sales volume, market share, customer satisfaction, and other performance improvements to the supply chain. Many practical cases have demonstrated that disruptive technologies can help supply chains cope with risks and provide solutions for risk response and recovery. However, supply chains also have to face the negative impact of disruptive technology. As such, supply chain managers and regulators need to determine how to give full play to the maximum advantages of disruptive technologies, avoid negative impacts, ensure the stability of supply chains, and improve the SCRes.

4.2 Management implications

For companies, the first step is to recognize the importance of disruptive technologies for SCRes. Companies must maximize the opportunity of automation and intelligent construction as well as carry out innovation and application around the latest disruptive technologies. The cost of constructing disruptive technologies is inevitable, as these expenses may include the cost of the research and development of the technologies, the cost of updating and iterating on technologies, the cost of leasing and purchasing the technologies, and the cost of hiring employees with the relevant knowledge and skills (Reddy and Reinartz, 2017; Davenport and Ronanki, 2018). However, disruptive technologies can enhance value for companies by reducing their spending on information and communication, human activity, and SCRes. Most importantly, it helps solve their primary concern: Uncertainty risk (Raguseo, 2018). Second, companies need to solve the risks caused by disruptive technologies. On the one hand, companies can comprehensively apply disruptive technologies to complement the shortcomings of a certain technology, thus improving the SCRes in terms of reliability. For example, the IoT and blockchain solve problems regarding privacy, security, and reliability of data. Moreover, the IoT and AI solve problems in data collection and analysis. On the other hand, companies should cooperate with one another to develop and apply disruptive technologies. The aim is to improve the coordination of supply chains and avoid risks caused by the digital divide and different technical standards among members. Finally, companies should focus on improving the usefulness of technology in the supply chain. They must carry out the construction of infrastructure, including improving data sharing with other supply chain members, interconnecting with large data platforms, and building intelligent facilities. It can provide a good foundation for the application of disruptive technologies in the SCRes.

The government should encourage companies to innovate and apply new disruptive technologies to improve the maturity of technologies. Perhaps, the government can provide financial subsidies and policy support to companies that undertake disruptive technology innovation and research and development investment. This support not only helps companies reduce innovation costs but also enhances the SCRes. At the same time, the government should also help companies share the risks caused by the application or innovation of disruptive technologies. In particular, it should help companies solve the problems of the digital divide and inconsistent standards among supply chain members. For example, the government can encourage supply chain members to open data resources and build a unified government data-sharing platform. These solutions can help achieve information connectivity among supply chain members and enable the members to participate in the construction of the SCRes.

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