

# Enhancing Supply Chain Resilience: The impact of Blockchain & Emerging Technologies on Traceability

Manikandan Selvaraj<sup>1</sup>, Rohit Raman<sup>2</sup>

<sup>1</sup>Senior Product Manager, Amazon Inc.

<sup>2</sup>Senior Consultant, PricewaterhouseCoopers (PwC) Advisory Services LLC

## Abstract

Supply chain traceability is an invaluable tool for companies to gain a competitive advantage today. The ever-changing global business environment, unpredictable market conditions, and changing consumer preferences call for agile supply chain systems. The pandemic helped reveal the vulnerabilities within the supply chain networks that need addressing. Various challenges, such as data reliability and integration, affect the current supply chain traceability and must be addressed. Such factors lead to inefficiencies within the system, which affect the process and lead to inconsistencies. The paper uses a systematic literature review to identify recent challenges and solutions to supply chain traceability. An analysis of blockchain technology's role in promoting transparency and security in supply chain systems was conducted. Lastly, an in-depth analysis of how improving traceability can help the supply chain networks build resilience.

**Keywords:** Supply Chains (SCs), Supply Chain Management (SCM), Supply Chain Systems (SMS), Supply Chain Traceability (SCT), Blockchain Technology

## 1. Introduction

Supply chain traceability plays a vital role in identifying and tracking goods and merchandise as they move from the point of production to distribution. However, Supply Chains (SCs) have become complex in recent years due to globalization and evolving market needs. The complexity introduces loopholes within the system, affecting risk and causing disruptions. The issues affect supply chain traceability, making it impossible to trace the systems, ensure sustainability, and manage risk [13]. Some of the issues driving change in supply chain management include the shift from an owner-driven industry to a customer-centered model. Therefore, consumers determine which SCs to use, paying attention to the quality of the products, loyalty to brands, and trust. The shift increases the pressure on the SCs and increases the need for traceability. The other issue is digital technology, which has benefits and drawbacks. On the positive side, it helps in various ways, including automation and inventory management. However, on the negative side, it also demands transparency and traceability to make it effective [7]. It is thus vital to identify the challenges and find sustainable solutions to promote supply chain traceability.

There is, however, a dearth of knowledge regarding the current issues faced by Supply Chain Systems (SCs). Multiple factors affecting the traditional and digital SCs necessitate understanding and addressing them. Some include the recent pandemic that affected many SCs as they lack resilience, the emergence of

the global supply chain networks, and the shift to a consumer-centered model. Many supply chain managers utilize technological tools, including blockchain technology, to adapt to changing needs and build visibility and traceability. However, little understanding exists of its benefits and role in promoting supply chain traceability. The lack of knowledge presents challenges such as data reliability and the adoption of blockchain technology. The paper aims to explore the issue of supply chain traceability and how it affects resilience. The specific objectives include:

RQ1: What are some challenges in Supply Chain Traceability (SCT)?

RQ2: What are the solutions to the challenges faced in supply chain traceability?

RQ3: What is the role of blockchain technology in enhancing security and transparency in supply chain traceability?

RQ4: How does improved traceability improve supply chain resilience?

## 2. Research Methodology

A systematic literature review was a vital methodology that helped gather different sources and examine the current issues and solutions to the problem. According to [18], a systematic review helps eliminate bias and improve thoroughness in examining the issue through different sources. The first step was determining the purpose of the study following the formulated objectives. The goal is to explore supply chain traceability, identify challenges and solutions, identify the impact of blockchain technology, and determine how improved visibility creates resilience. The inclusion criteria used are finding sources that are peer-reviewed, current, relevant to the topic, and from reputable publications. Studies excluded were those that were not relevant to the subject matter. After identifying the purpose and criteria, the next step was identifying the articles using the Boolean search strategy and keywords within the EBSCOhost, Wiley, and SpringLink databases. The fourth stage included selecting the relevant studies by analyzing the list of articles. Over 1319 articles were identified in the initial search. The list was narrowed after including the filters such as year of publication, language, relevance, and credibility. Reading the abstract and conclusion helped to determine relevance. A total of 16 articles were selected for the review. Then, data extraction took place using a Microsoft Excel spreadsheet to identify the data from each study. The primary findings were then analyzed and integrated into the research paper to answer the questions.

## 3. Challenges in implementing Supply Chain Traceability Systems

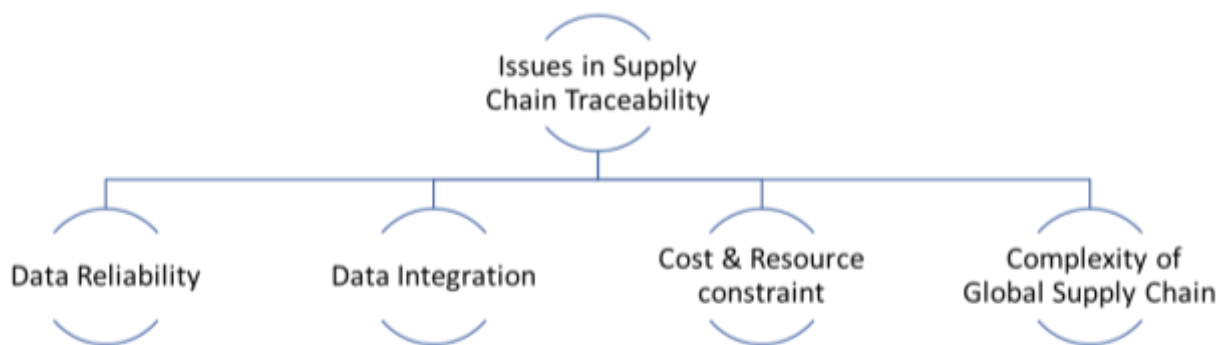


Figure 1: Challenges in Supply Chain Traceability

### A. Data Reliability Issues

Traceable systems create transparency that builds trust between stakeholders and clients. The success of the SCs relies on accurate and complete data. Data reliability issues challenge trust, creating problems in

inventory management and maintaining accurate records. Today, most SCs incorporate technology in their operations, which increases operational efficiency. However, it also presents some risks. According to [7], fraud cases are expected when working within a centralized information system, as people can tamper with the records, contracts, receipts, and debit notes. Such cases affect decision-making and the development of trust with stakeholders. The other impact of data reliability issues is the failure to comply with regulations, which poses legal challenges for the companies. Moreover, the global nature of the supply chain today makes the issue complex, given the different stakeholders, geographical regions, and regulations in play. It is hard to track data reliability and ensure each party is accountable. Thus, a sophisticated system is needed to ensure that all players within the global supply chain keep credible, valid, and accurate data.

### **B. Data integration challenges**

Integrating data from the various sources of the supply chain network is complex when developing the traceability system. Different stakeholders along the supply chain use different data formats and technologies, making it hard to integrate them. As Figure 1 shows, data reliability issues affect the integration and quality of data. After analyzing the supply chain integration models, [16] determined that most companies only model part of the complexity of the supply chain network, leaving loopholes that make integration hard. It is loopholes that cause challenges affecting traceability. Therefore, the traceability systems must be seamless, allowing information flow throughout the supply chain. The strategy improves transparency and monitoring, which enhances data reliability. For example, the US Drug Supply Chain Security Act requires end-to-end traceability for prescription drugs. However, the biggest challenge in enforcing the act is integrating data and tracking it from the manufacturer to the wholesalers and pharmacies, which is proving challenging. The issue led to prescription drug abuse affecting the US population, leading to overdose and addiction [4]. The loopholes within the system make it hard to trace, identify, and fix issues. One action within the supply chain system affects the stakeholders and presents public health issues. Thus, Data integration is essential to traceability as it offers data that inform decision-making.

### **C. Cost and resource constraints**

Cost and resource constraints affect Supply Chain Traceability (SCT). Implementing the traceability systems is resource-intensive. Setting up, testing, training, and maintaining the system requires money and resources. Supply chain companies and networks of small and medium businesses invest in inferior traceability systems. Such decisions lead to ineffective tracing, which affects business growth. Also, the difference in traceability systems leads to disparities within the network, making it hard to get reliable data, integrate it, and trace it. For most companies, the return on investment for the traceability system does not make sense since there are no direct short-term returns. However, it costs the business more money to fix the traceability issue in the long run than investing in a sound system. Resistance to change among some stakeholders in adopting the best technology contributes to the problem. Traceability relies heavily on collaboration and cooperation among the stakeholders, and the inability to adopt the best technology affects the network. A case example involves Walmart's adoption of RFID. They mandated that their suppliers adopt the technology as well. There was resistance due to the system's costs, which led to delays that affected the supply chain network [15]. The issue of traceability systems needs to be approached collaboratively to become effective. Companies need to ensure that their entire network uses the same system. However, attaining uniformity takes time and effort.

#### **D. Complexity of the global supply chain networks**

One of the significant challenges in the world today is globalization and its impact on the supply chain system. Businesses are expanding to new territories, and challenges to ensuring supply chain traceability come with the expansion. One of the characteristics of the global supply chain is the multiple tiers of suppliers within different regions with varying regulations. Navigating the different dynamics can present a challenge to most companies. Capacity plays a role in traceability, and the lack of a typical working culture can affect traceability as other nations have varying technologies and resources to implement traceability systems. The situation leads to disparities that affect traceability, posing a challenge in managing the global supply chain systems. According to [1], global supply chains are risky due to exposure to foreign shocks. Examples of the shocks include natural disasters, the recent pandemic, and restrictions and regulations. Companies need to consider the risks of the global supply chain and the complexities they present and include them in the design process. The intervention ensures that risk mitigation becomes part of the traceability system, and thus, the companies can address the shocks as they come.

### **4. Solutions to overcoming Traceability implementation issues**

#### **A. Training and Capacity-Building**

Training and leadership initiatives have the potential to create capacity within the SCT systems to manage the global supply chain systems. The training, especially in leadership, helps address SCT's many challenges, such as data reliability, stakeholder resistance, and adopting new technologies. Reference [14] reviewed research and found that learning is vital in promoting supply chain management and traceability. One of the ways it helps is by allowing companies to implement sustainable initiatives such as blockchain technology by raising awareness on such matters. The education and training enable stakeholders to understand sustainability and adopt strategies that match the goals. Tailored training among the SCT stakeholders is vital to teaching them the context-specific contingencies and practices that promote the adoption of the best traceability technologies, data reliability methods, and conformity to industry regulations. Training the different teams in companies with global supply chain systems helps ensure conformity within the chain. The leaders set the culture in motion by leading by example and inspiring the other stakeholders to follow. Another benefit of the training is imparting practical data authentication and digital labeling skills. The stakeholders need to learn how to label the products effectively to create consistency that improves end-to-end visibility and traceability [9]. In data authentication, the stakeholders lead to publishing data throughout the supply chain, improving accuracy and integrity, which is critical in data validation. Therefore, the training empowers leaders and stakeholders and upskill their skills and knowledge to engage in effective strategies that address SCT challenges.

#### **B. Technological investment**

Technology is transforming SCT through the use of blockchain technology. The technology cultivates trust, traceability, and transparency by improving the flow and efficacy of the supply chain systems. One of the ways blockchain helps with traceability is by reducing resource consumption. The transparent ledger contained in the system ensures that stakeholders can trace data in real-time, guaranteeing its integrity. The other benefit is the creation of standardized methods to record and share data, promoting data integration along the supply chain networks. An example of such companies includes Coca-Cola, which, together with BanQu, launched a blockchain-based platform that empowers waste collectors and small sales centers in South Africa. Online tracking technology helps Coca-Cola track recycled materials

throughout the supply chain system [17]. The action promotes transparency for all stakeholders, promoting trust and improving decision-making quality. It creates an integrated system that links different stakeholders, enhancing accountability and data reliability. In doing so, blockchain technology reduces costs and redundancies, making SCT cost-effective in the long run. The other technological investment includes generative artificial intelligence, which helps the company analyze data and mitigate risk. Generative AI analyses the large volumes of data within the supply chain systems and identifies vital anomalies and patterns in data validation and decision-making. They can detect anomalies and alert the companies to take proactive action to mitigate the risks. It also helps track inventory and prevent cases of fraud along the supply chain. Such data addresses resistance from stakeholders who may be critical in promoting collaboration, trust, and transparency.

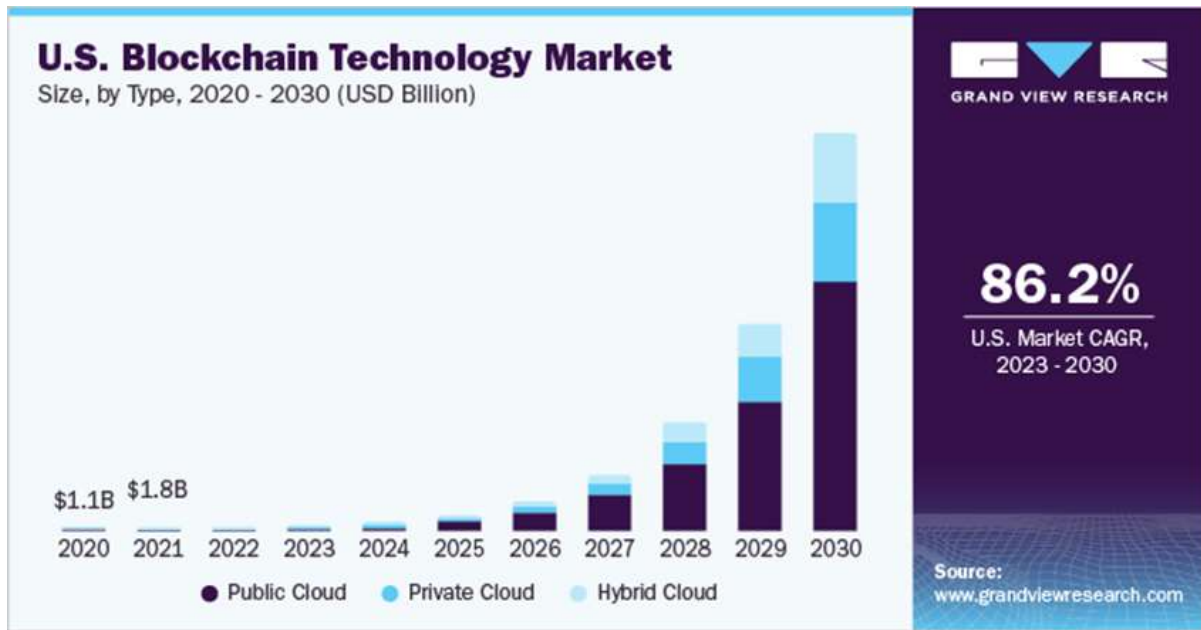
### **C. Collaborative approaches**

Collaborative approaches play a critical role in addressing issues of cost, resistance to change, and the complexity of the global supply chain. The strategy involves stakeholders working closely and creating beneficial partnerships among suppliers, peers, clients, and competitors. One of the benefits of collaborative approaches in the supply chain system is the economies of scale, where risks and benefits are spread. Companies can afford the most expensive technologies, such as AI and blockchain when they come together through collective bargaining and contributions. Data integration becomes seamless since the partners use the same system and standardization process. Reference [9] provides a case example of a collaborative approach to traceability in the Sustainable Apparel Coalition's Higg Index. The collaboration brings together different stakeholders within the apparel and footwear brands. The relationship offers standardized sustainability measurement tools that all shareholders enjoy. Traceability measures, for example, have been optimized to reduce the harmful impacts of the SCS. The other finding was the impact of acquiring new technology due to the long-term collaborative planning. The companies' risk mitigation strategies arise from collaborative decision-making and resource pool, making the Sustainable Apparel Coalition resilient in times of crisis in the global supply chain system.

### **5. Role of Blockchain in enhancing Supply Chain Traceability**

Blockchain technology promotes transparency and security in supply chain systems. Its application is becoming prevalent in different industries across the globe. According to [4] findings, the current market value is 17.46 billion and is expected to grow at an annual rate of 87.7%. In the evolving landscape of trade, SCM has become complex. Figure 2 shows that the rate will rise in the coming years. Issues of rapid globalization and the demand for transparency, traceability, and secure supply chains necessitate agility to adapt to changing needs. Blockchain technology creates a decentralized, distributed ledger system that records transactions across the supply chain using computers and devices. Such ledgers are immutable, which helps to keep the data safe and ensure all participants have access [12]. The nature in which the technology is built makes it impossible to alter the transactions retroactively. It thus plays a vital role in promoting secure, traceable, and effective supply chain systems.





**Figure 2: Blockchain Technology Current and Expected Growth**

The other role of blockchain technology is that it offers real-time visibility across the supply chain. Unlike the traditional model, which is fragmented and lacks transparency, blockchain technology provides transparency that allows for easy tracking and movement of goods from one place to another. The unique digital identity makes it easy to trace products, enabling the companies to do quality control and understand where the problems stem [12]. The technology eliminates intermediaries within the system, reducing the risk and security issues from man brokers. There is increased accountability in such a model due to the stakeholders' transparency. The other important role has to do with improved collaboration. The availability of credible and valid data alongside openness makes it easy to share information seamlessly. The impact was that I improved trust and cooperation between the partners.

**A. How Blockchain Technology Can Provide Transparency and Security in Supply Chains, Preventing Fraud and Counterfeiting.**

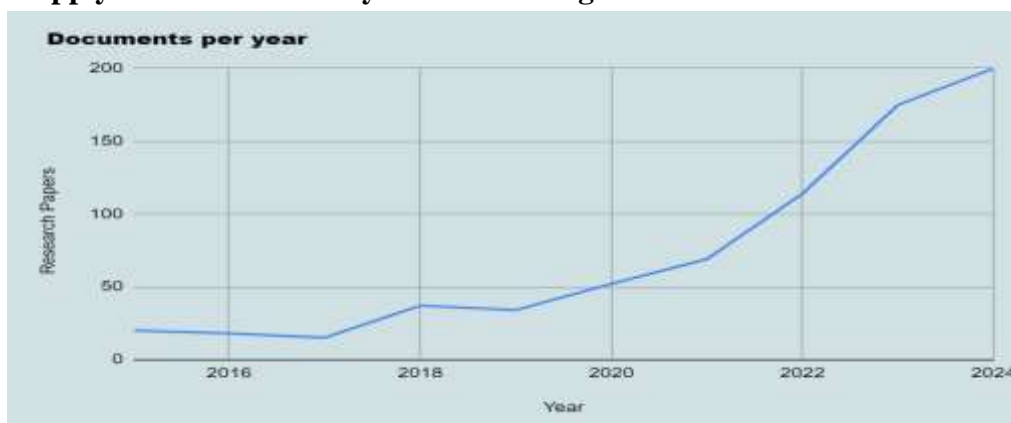
Consumers demand that products, their origins, production processes, and the nature of the materials be understood, which necessitates a transparent supply chain system. Blockchain technology offers immutable records of the merchandise journey from production to the final distribution, which promotes transparency. The other aspect of the technology is a peer-to-peer network, which ensures interoperability as each node maintains a copy of the ledger. Thus, there is synchronization within the supply chain network. Regarding security, blockchain technology can address the limitations of the traditional system. Conventional systems have experienced fraud, data tampering, and breaches, making them ineffective and insecure. Blockchain technology has encryption linked to previous transactions, which helps form the chain of blocks. In a study to develop blockchain technology that would enhance transparency, Reference [2] revealed that the technology promoted openness as all the stakeholders had access to information, fostering trust in the network. One of the ways that the technology was promoted was by promoting upgraded records, which ensured that data on customers, delivery time, and price was present, facilitating the process. It reduced the costs of products and increased the market share as the system was efficient. There are different properties of the blockchain technology that make it effective. One of them is the decentralized nature. The distribution of the ledger within the blockchain system ensures that all

stakeholders can detect any alteration of data. It is thus vital when tackling data corruption issues within the chain. It also overcomes the limitation of using the traditional centralized system where one party can control and manipulate the data. The property improves the trust and security of the data, making the supply change process valid and transparent [2]. The other property of blockchain technology is trust, a consequence of implementing the system. The distributed ledger system allows the partners real-time access to data. It also allows for privacy and anonymity, essential in creating secure systems. There are attributes of anonymity and privacy contained within the cryptography system. Enabling the property ensures the system's confidentiality and data security. The system maintains data records' integrity, promoting trust that ensures the system is working effectively.

Automation is a critical component of the blockchain system within the supply chain network. These characteristics make it possible for stakeholders to create smart contracts and verify them in real-time based on the set rules of engagement [2]. The smart contracts are found within the blockchain ledger. Once triggered, the contracts and content are broadcasted on the network for validation and updating. Automation, when it comes to smart contracts, reduces the time spent on creating traditional contracts. It increases efficiency as all participants get real-time updates, and communication is accessible. It thus reduces the cases of fraud that can take place when working with the traditional SCM model. Smart contracts create decentralization within the system, empowering all the participants. Therefore, no side deals are done as all participants are engaged in the process from the beginning to the end. Participants can thus trace the contracts and monitor them, promoting transparency.

One of the blockchain technologies is the Modum, a supply chain technology offering monitoring solutions to the stakeholders. According to [5], the technology helps track and control the distribution of sensitive products such as food and pharmaceuticals. It contains a sensor modicum temperature logger and an Ethereum network, which help form the back and front-end phases of the technology. Each ledger within the system has a unique Mac address in the QR code that helps track and monitor processes. Once the QR code is present, the stakeholders broadcast it within the SCS. The technology allows the clients to confirm the product specifications using sensor temperature measurement and Bluetooth light energy [11]. The client then sends the report, and the supply chain network can access the results. Such a technology promotes the system's transparency, trust, and traceability and ensures it is secure for all the stakeholders. Resolving issues within the network is timely, collaborative, and effective as client communication is enabled.

## 6. Impact of Supply Chain Traceability on Risk Management and Resilience



**Figure 3: Interest in Supply Chain Resilience over the Years**

There is a need for the supply chain systems to account for the disruptive events that may affect the operations. A study done to analyze the supply chain resilience during the pandemic revealed a need for more resilience. Most supply chain managers needed to prepare for the event, which affected their resilience after the pandemic. The pandemic thus revealed the vulnerabilities within the supply chain systems, one of them being the lack of visibility [10]. Most companies relied on lean inventory systems and also just-in-time replenishing. The strategies proved futile amid the pandemic as they were vulnerable to the shocks. The research into supply chain resilience intensified after many supply chain systems were affected during the pandemic. The adverse outcomes of the SCS after the pandemic made it necessary to look into the issue and determine how companies can become resilient. As Figure 3 shows, research intensified from 2018 to 2020. Before that, the number of documents produced yearly was less than 20. After the pandemic, resilience was emphasized as most SCs realized the effect of not having systems to ensure recovery. Figure 4 shows the different components of supply chain resilience, including risk management, resilience, and viability. The three elements work together to create resilience within the SCS.



**Figure 4: Supply Chain Resilience Components**

Risk management refers to assessing, developing strategies, and implementing measures to address potential disruptions to the business. On the other hand, resilience is the SC's ability to withstand and recover from the disruptions after they occur. The company must have strategies to foresee the events and bounce back. The third element, viability, refers to the ability of SCs to sustain themselves long-term despite the uncertainty and disruptions [6]. Risk management is the primal stage of building resilience and attaining SCs viability.

Supply chain traceability improves risk awareness due to visibility. Supply chain resilience has become necessary in the complex globalized business environment. According to [6], the current business environment is unable, given the recent pandemic in 2020. The incident emphasized the need for resilience, which ensures that the supply chain system is sustainable in the long term. Improved traceability plays a vital role in improving supply chain resilience due to the ability of the company to be aware of the risk and how to manage it. Traceability provides valuable data and updates that make it easy to make



decisions and adjust the system to meet the changing needs and push through the different market conditions. The improved visibility allows the company to be risk-aware and develop proactive strategies to address the challenges. According to [10], supply chain managers with improved traceability can identify disruptions occurring 37% faster than the average manager. The speed with which the supply chain managers spot issues play a vital role in developing proactive strategies to address the risk in the fast-paced business setting. Research done by [8] showed that identifying areas of vulnerability within the system determines the difference between the success or failure of a supply chain system. Supply chain managers can identify issues within the system and use the available data to trace and identify the relevant stakeholders, promoting accountability. Amid Industry 4.0, business processes are autonomous, automated, and intelligent, making getting feedback and resolving issues easy.

The other role of improved visibility is that it promotes proactive risk management. The role goes beyond identifying risks to developing strategies to mitigate them. Access to real-time data on the products and inventory is an invaluable resource that offers data on the origin of the issue and the stakeholders involved. The supply chain manager can thus engage the stakeholders in resolving the problem within the system. The data improves the quality of decision-making as the supply chain manager enforces relevant and targeted strategies to mitigate the risks. A study [8] showed that companies with improved traceability systems were 2-3 times more successful in mitigating risks than those without. The success is due to the ability to forecast issues through traceability. A study by [2] revealed that improved traceability played an essential role in quality control in the food industry. The ability to trace products allows supply chain managers to identify vulnerabilities, including food contamination, within hours. The timely discovery of the source of the issue helped reduce the scale of product recall, and companies can get ahead of issues and resolve them. Therefore, improved visibility is vital to resolving problems and mitigating risk to ensure the supply chain system remains resilient. It helps to reduce reputation damage to the organization and any other losses from legal complications in product recall, strengthening the supply chain system and keeping it stable.

Supply chain traceability helps to promote adaptive capacity and resilience in the SCS. The system can adjust, become flexible, and reconfigure to the changing conditions in the market, within the system, and in terms of changes in consumer needs. The data collected within the supply chain system helps to inform decisions, making it easy to change and adjust the system to meet the changing needs. According to [10] findings, companies with improved traceability systems can redesign their supply networks 40% faster than ordinary supply chain systems. The agility created allows the systems to maintain high operations standards amid disruptions, making the ability to recover from significant events. Tracking data through improved visibility enables the supply chain managers to simulate the different scenarios and prepare effectively. Incorporating AI within blockchain technology allows for the simulation of other scenarios that make forecasting easy and effective [6]. The data created during simulation helps the company to develop capacity and remain agile, which ensures resilience in the long term. The ability to be nimble, adapt, and utilize data promotes resilience, allowing the companies to remain operational while those without are struggling.

## 7. Conclusion

Supply chain systems are continuously evolving, with technology playing a pivotal role in this transformation. Blockchain technology is a key tool in revolutionizing supply chains by ensuring data reliability and integration. It addresses traditional challenges such as data reliability and communication

issues by providing a hybrid platform that combines centralized and decentralized features. This platform allows stakeholders to input and access data, ensuring transparency and security, as data is difficult to alter or manipulate. Despite its benefits, blockchain technology can be expensive and complex to implement. However, with proper training and collaboration, organizations can leverage economies of scale to adopt this technology effectively. Beyond addressing supply chain challenges, blockchain technology enhances cost efficiency and collaboration over time. It also bolsters data security, making data more reliable for decision-making. The technology's tracking capabilities help prevent fraud and counterfeiting by enabling partners to trace goods and identify wrongdoers. Improved visibility is crucial for risk management and building resilient supply chains. Real-time traceability data reveals system vulnerabilities, promoting risk awareness and enabling supply chain managers to develop proactive and reactive strategies for unexpected disruptions. This adaptability and flexibility allow supply chains to respond to both internal and external market changes effectively, unlike traditional rigid models.

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