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Resilience of supply chains for essential goods and services

Bright Ojo *

Department of Operations Management, University of Arkansas, Fayetteville, AR, USA.

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Abstract

Reliability of the supply chains for products and services that are critical to any given nation is vital to security and people's well-being. This paper aims to discuss how the vulnerability of the supply chain for basic products including food, water, and pharmaceutical products can be reduced. Some of these are diversification, stock management, and technology such as blockchain and IoT. A detailed discussion of the effects of the COVID-19 pandemic and other similar occurrences on supply chains is provided to stress the need for resilience. The paper also analyses the measures and policies applied by the government to enhance supply chain management and the suggestions for further development.

Keywords: Supply Chain Resilience; IoT (Internet of Things); COVID-19 pandemic; Essential products and services; Sustainability; Vulnerability

1. Introduction

Supply chain resilience refers to the ability of a supply chain to proactively manage disruptions and effectively respond to and recover from them (Govindan et al., 2024). The importance of maintaining resilient supply chains cannot be overstated, as disruptions can significantly impact national security, health, and economic systems (Li et al., 2023). The globalization of supply chains has heightened their exposure to various risks, such as natural disasters, outbreaks, and geopolitical tensions, which threaten the availability of essential products and services (Wieland & Durach, 2021). The COVID-19 pandemic exposed the vulnerabilities within global supply chains, underscoring the critical need for resilience (Wieland & Durach, 2021). This paper focuses on exploring the measures and tools that can be employed to strengthen supply chains, with a particular emphasis on the food, water, and pharmaceutical industries. By evaluating recent events and analyzing government policies, the study aims to provide recommendations for enhancing supply chain resilience in the face of these challenges.

1.1. Purpose of the Study

The objective of this research is to assess the impact of different approaches and tools in improving the supply chain vulnerability for necessities. The study also seeks to establish the drawbacks and limitations of the above strategies and give policy implications for enhancing supply chain preparedness.

1.2. Research Question

What measures and tools can contribute to the improvement of the supply chain for critical products and services, and what are the problems and opportunities in their application?

1.3. Research Objectives

To evaluate the effectiveness of different measures and tools concerning supply chain vulnerability.

* Corresponding author: Bright Ojo

To establish the difficulties and drawbacks of the implementation of these strategies.

To offer comprehensive policy implications for strengthening the supply chain, and for uninterrupted availability of goods and services.

2. Literature Review

2.1. Importance of Supply Chain Resilience

Supply chain disruptions result in shortages, increased prices for goods, and consequently, public unrest (Govindan *et al.*, 2024). For instance, the COVID-19 pandemic interfered with the supply chain of PPE materials, resulting in a shortage and high cost of the products, showing the relevance of supply chain sustainability (Li *et al.*, 2023). Resilience is crucial for the prevention and ability to bounce back in the event of disruptions in the delivery of health, safety, and economic systems (Hosseini, Ivanov, and Dolgui, 2019). Supply chain resilience is not only a recovery capability but also a way of sustaining supply chain operations amidst the risks (Liu, Lee, and Lee, 2020). It entails sound management, contingency, and adaptability strategies to ensure that disruptions are well managed. It has attracted much attention since it plays a central role in managing the effects of natural disasters, conflicts, and economic crises. The ability to quickly and effectively respond to changes in conditions also allows for the supply chain to remain operational and deliver the necessary goods and services with little disruption (Wieland and Durach, 2021).

2.2. Strategies for Enhancing Supply Chain Resilience

There are various ways through which the supply chain can be made robust for the delivery of essential goods and services and these are diversification, optimum stocking, and technology integration (Hendry *et al.*, 2019). Diversification entails the distribution of the risk of supply in terms of suppliers and places where the products are made (Govindan *et al.*, 2024). It also guarantees that a breakdown in one segment of the supply chain does not have to bring down the entire process. Some measures can be taken by the companies to eliminate the dependency on a single source such as selecting different suppliers, locations, and transportation channels (Liu, Lee, and Lee, 2020). For instance, the disaster response of Toyota company after the 2011 Tohoku earthquake included a change in the supplier base so that future shocks would not significantly affect production. Thus, this approach enabled Toyota to sustain production rates even though the earthquake negatively impacted the manufacturing process (Wong *et al.*, 2020). Strategic stockpiling is the act of keeping buffer inventories of goods that are vital to the supply chain. This strategy can assist in guaranteeing the constant supply of basic products during calamities. A strategic stockpile serves as a backup that enables supply chains to run as normal even if production or distribution is stopped for some time. During the period of the COVID-19 outbreak, countries with an effective strategic inventory of PPE and medical products experienced less pressure to procure these goods (Hendry *et al.*, 2019). These stockpiles offered a form of insurance that enabled the healthcare systems to operate optimally during the crisis (Ozdemir *et al.*, 2022).

Modern technologies like blockchain and the Internet of Things (IoT) may improve supply chain performance and its resistance. It is also characterized by high degrees of transparency and a record of transactions that cannot be altered, which increases accountability (Stone and Rahimifard, 2018). It also provides a tracking system of the goods and materials to detect any hitches at the earliest instance possible (Ribeiro and Barbosa-Póvoa, 2019). For instance, IBM's Food Trust blockchain services are used by Nestle and Carrefour and have led to cutting food fraud by 31% and time on food products' origin by 50%. It assists agricultural companies in meeting regulation laws such as FSMA, and it enables the consumers to have confidence in the agricultural products as regards sustainability and safety (Burgos and Ivanov, 2021). This way IoT devices can track the condition of the goods in real time and give early indications of disruption (Alfarsi, Lemke, and Yang, 2019). For example, smart sensors are capable of identifying changes in the temperature of perishable products to prevent spoilage (Ozdemir *et al.*, 2022). IoT technology also helps to predict the failure of the equipment and avoid such failures. In the water industry, IoT sensors are applied to measure the quality of water and also to check the leakage of water in real-time so that there will be no loss of water and the water supplied will also be safe. These technologies can be of great value in the preservation of the supply chain's credibility as well as the optimization of its operations (Wong *et al.*, 2020).

2.3. Case Studies

2.3.1. COVID-19 Pandemic

The COVID-19 pandemic provided people with the lessons of the vulnerability of global supply chains and the importance of developing relevant protection (Aslam *et al.*, 2020). There have been supply shocks in the PPEs, food, and medicine markets due to disruptions in the supply chain. The pandemic also underscored the value of having

diversification and building up strategic inventories. Those countries and companies that had spread their supply chain risks and kept buffer stocks fared better during the disruptions (Ribeiro and Barbosa-Póvoa, 2019). For example, the WHO highlighted that the international community experienced severe disruptions of essential health products such as PPEs, test kits, and ventilators which worsened the effects of the pandemic (Aslam *et al.*, 2020). Countries like South Korea which had strong reserves and a great variety of supply sources performed better in the crisis. They could mobilize stored resources and redirect supply chains toward areas with lower impact, which proves efficient preparedness (Jabbarzadeh, Fahimnia, and Sabouhi, 2018). The pandemic also influenced the adoption of new technologies for supply chains and their development. Blockchain was used to enhance supply chain visibility and IoT for monitoring the state of supply chain conditions. For instance, Pfizer employed blockchain to guarantee that the COVID-19 vaccines were delivered at the right temperatures and that every shipment was monitored in real-time (Aslam *et al.*, 2020).

Table 1 Impact of COVID-19 on Global Supply Chains (Xu *et al.*, 2020)

Impact Metric	Before Pandemic	During Pandemic	Percentage Change
Availability of PPE	High	Low	-60%
Prices of Essential Goods	Stable	Increased	+30%
Adoption of Blockchain Technology	Limited	Expanded	+50%
Real-time Monitoring using IoT	Limited	Expanded	+40%

2.3.2. Natural Disasters

Certain calamities, for instance, hurricanes or earthquakes, can often lead to the disruption of the supply chains for basic needs. For instance, Hurricane Katrina which occurred in 2005 affected the supply of fuel and subsequently the prices (Macdonald *et al.*, 2018). Such calamities bring out the need to diversify as well as strategically stock important items. Companies can be able to source their stocks from different suppliers and also have strategic stockpiles that will enable them to have stocks that are required in emergencies (Jabbarzadeh, Fahimnia, and Sabouhi, 2018). The earthquake and the Tsunami in Japan in the year 2011 affected the global supply chain, especially in the automobile and electronics industry. Large firms such as Toyota and Sony were affected severely as they stopped production since most of their suppliers were in the affected areas. These companies were forced to expand their supplier pool, build up inventories locally, and create better contingency scenarios to avoid similar risks in the future. Toyota's risk management plan in response to the 2011 disaster was the diversification of suppliers, the accumulation of a larger stock of parts, and the creation of regional centres to diversify production. These measures have enhanced the Toyota firm's preparedness, and this has enabled the firm to continue with its operations during other disruptions (Burgos and Ivanov, 2021).

Table 2 Impact of Natural Disasters on Supply Chains (Burkhardt, 2021)

Natural Disaster	Sector Affected	Impact	Mitigation Strategy
Hurricane Katrina (2005)	Fuel	Shortages, Increased Prices	Diversification, Strategic Stockpiling
Tohoku Earthquake (2011)	Automotive, Electronics	Production Halts, Supply Chain Disruptions	Supplier Diversification, Local Stockpiles, Regional Hubs

2.3.3. Government Initiatives

Governments have embarked on various measures to increase supply chain responsiveness. For instance, the Executive Order on America's Supply Chains signed by Biden in the year 2021 seeks to increase the supply chain vulnerability of food, pharmaceuticals, and semiconductors. The order requires federal agencies to review risks in the supply chains and design ways of managing risks (Macdonald *et al.*, 2018). Supply chain management can be significantly improved by the willingness of governments to fund, support, and even regulate such critical areas. The European Union has also come up with plans like the European Chips Act to cut down on outsourcing for semiconductors by promoting local manufacturing. These are some of the measures being taken to improve the reliability of vital technology supply chains against geostrategic threats as well as market volatility (Stone and Rahimifard, 2018). Besides the legislative actions, the governments have also put their efforts into supply chain security through public-private partnerships. For instance, the US Department of Defense has partnered with private companies to ensure the supply chains for strategic goods

such as rare earth metals, which are crucial to national security and technological advancement (Jabbarzadeh, Fahimnia, and Sabouhi, 2018).

Table 3 Government Initiatives to Enhance Supply Chain Resilience (Hsu *et al.*, 2022)

Government Initiative	Description	Impact on Supply Chain Resilience
Executive Order on America's Supply Chains	Directs federal agencies to assess and strengthen supply chain vulnerabilities	Enhances national security and public health preparedness
European Chips Act	Fosters local semiconductor production to reduce dependency on external suppliers	Increases resilience of critical technology supply chains
Public-Private Partnerships	Collaborations between governments and private sector companies	Secures supply chains for critical materials and technologies

3. Methodology

3.1. Research Design

This research uses a mixed research approach that incorporates both quantitative and qualitative methods in measuring the impact of strategies and technologies in improving the resilience of supply chains. Primary data were gathered using questionnaires administered among the supply chain managers and technology providers in the food, pharmaceutical, and water industries. The qualitative data collection method used in the research involved interviews with the relevant stakeholders which included the industry pundits and policymakers. This approach to the research provides a rich and holistic way of answering the research question by incorporating quantitative data with qualitative data from the industry (Krippendorff, 2019). This design improves the credibility of the data collected since data is collected from different sources and not just from the students alone (Popkova, Ekimova, and Sergi, 2020).

3.2. Data Collection

The quantitative data were collected through survey questionnaires, which were developed based on the supply chain resilience framework and the identified strategies and technologies. The questions in the questionnaire were related to the application of various strategies, the advantages, and the problems encountered. The target audience of the sample was the supply chain managers and technology suppliers across the industries. The qualitative data were obtained from the interviews with the key stakeholders conducted according to the semi-structured interview guide. The interviews aimed to identify the participants' practice of applying strategies and technologies to build supply chain resilience, their advantages and disadvantages, as well as the recommendations for increasing supply chain resilience (Popkova, Ekimova, and Sergi, 2020). This way, the integration of quantitative and qualitative data gives a solid ground for evaluating the impact of resilience measures (Pluye *et al.*, 2018). Quantitative data gives results in figures while Qualitative data gives results in words, phrases, and descriptions (Gustafsson and Korhonen, 2022).

3.3. Data Analysis

Quantitative data were analysed by using descriptive statistics to describe the changes that resulted from the strategies and technologies concerning supply chain resilience. Descriptive statistics included mean, median, and standard deviation which explained the central tendency and spread of the data. Descriptive statistics such as the mean and standard deviation were used while inferential statistics such as chi-square tests and t-tests were used to compare variables. The interview data collected were analysed using thematic analysis. This method involves analysing the data to assign codes that will help in determining the patterns and themes that are inherent in participants' accounts. This approach of analysis enables the researcher to determine different themes about the advantages, disadvantages, and future outlook of strategies and technologies that can be applied to improve the supply chain. The use of quantitative and qualitative data ensures that the study is comprehensive as it captures all the aspects that affect supply chain resilience (Gustafsson and Korhonen, 2022).

3.4. Ethical Considerations

The participants were told about the objective of this research and the part they were going to play, and they were told they were free to pull out at any one time. Particular attention was paid to participants' anonymity, and all the results were presented in a way that excluded any possibility of identification. The respective ethical clearances were sought

from the institutional ethical review committee. The ethical consideration of the study makes sure that the research is done sensibly and correctly without violating participants' rights and their privacy (Char, Abràmoff, and Feudtner, 2020).

4. Results

4.1. Implementation and Effectiveness of Strategies and Technologies

The use of various strategies and technologies has improved the reliability of supply chains of goods and services necessary for people. This section includes actual cases from different industries to demonstrate the efficiency of these strategies and technologies.

4.2. Food Industry

The strategies that have been put in place by the food industry to increase the supply chain robustness are as follows. There has been a diversification of suppliers and production locations to decrease vulnerability (Rueda, Garrett, and Lambin, 2017). General stockpiling of vital products has helped act as a hedge during calamities. New technologies including blockchain and IoT have enhanced the tracking of products and real-time monitoring. For instance, IBM's Food Trust blockchain platform is implemented by Nestle, Carrefour, and other giants; it helps to minimize food falsification by 31%, and it takes half the time to trace the food source (Ada *et al.*, 2021). This level of transparency assists the agricultural companies in adhering to the provisions of regulations like the FSMA and, therefore, builds trust among consumers in the sustainability and safety of the foods they consume. The execution of these strategies has also been associated with cost containment and effectiveness gains. For instance, the reduction of food fraud has reduced the need for more audits and inspections hence time and cost savings. Owing to this, it has also become easier to track the source of food products in case of recalls hence reducing the losses from such incidents to companies (Rueda, Garrett, and Lambin, 2017).

4.3. Pharmaceutical Industry

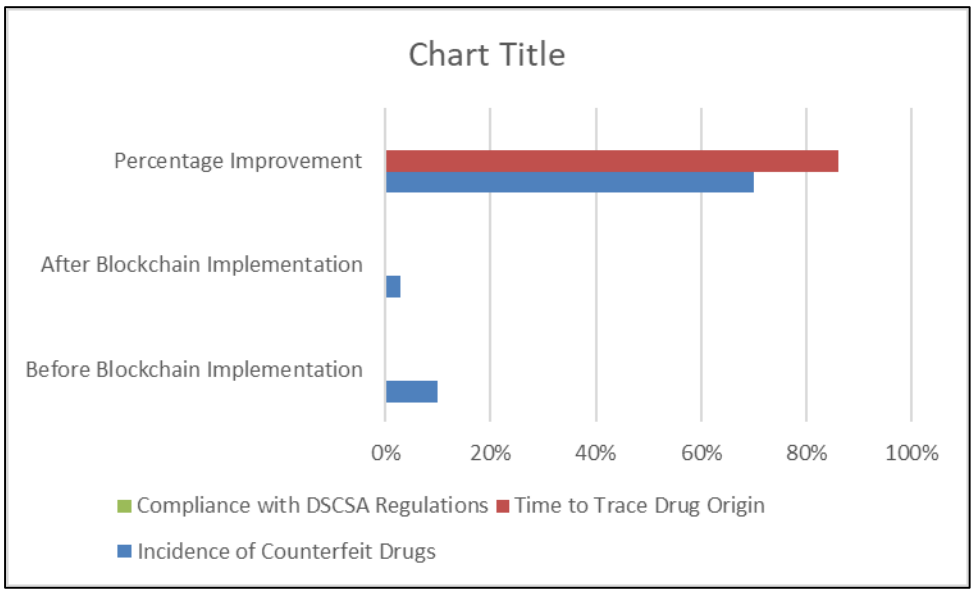

Figure 1 Impact of Blockchain on Pharmaceutical Supply Chains (Clauson *et al.*, 2018)

Blockchain technology has been adopted in the pharmaceutical industry to record the source and genuineness of drugs and this has greatly minimized counterfeiting. In terms of emergency rational procurement has helped to develop a stockpile of essential drugs. The industry has also worked on the suppliers' diversification and production sites to avoid interruptions (Abbas *et al.*, 2020). The World Health Organization has estimated that counterfeits make up between 5% and 10% of the global pharmaceutical market. IBM and KPMG's blockchain platforms have managed to cut the instances of fake drugs in the monitored supply chains by 70%. It also offers a means of recording all the transactions to ensure that every pharmaceutical product can be traced back to its source, thereby increasing the safety and reliability of the pharmaceutical chain (DiMasi, Grabowski and Hansen, 2016). Blockchain technology has also enhanced the level of compliance with the regulatory frameworks (Clauson *et al.*, 2018). The DGSCSA in the United States of America requires

the implementation of traceability of prescription drugs through the supply chain. Thus, using the principles of distributed ledger technology, blockchain allows pharmaceutical companies to meet the above-mentioned regulatory requirements and enhance the security of the drug supply chain (Abbas *et al.*, 2020).

4.4. Water Industry

The water industry has also adopted several measures to increase the supply chain's robustness. Concerning the diversification of water sources and strategic stockpiling of such materials as chemicals and equipment, the risk has been minimized. Technologies like the IoT have enhanced the monitoring of water quality and the structures in use in real time (Rieth and Dincă, 2018). For instance, smart water management systems that include IoT sensors are capable of identifying leakages and the quality of water supply in real-time hence minimizing loss of water and ensuring the availability of safe water supply. These systems have been employed and, in turn, have caused a decrease in water losses by 20 percent and the response time to any emerging problems by 25 percent. These strategies have also enhanced the effectiveness and sustainability of water management in the implementation of the strategies (Pal and Gander, 2018). Real-time monitoring enables early detection and maintenance and reduces the instances of major repairs and thus the impacts on the environment. It has also been possible to manage the resources well, especially the use of water and energy in the provision of products through the application of IoT technology (Rieth and Dincă, 2018).

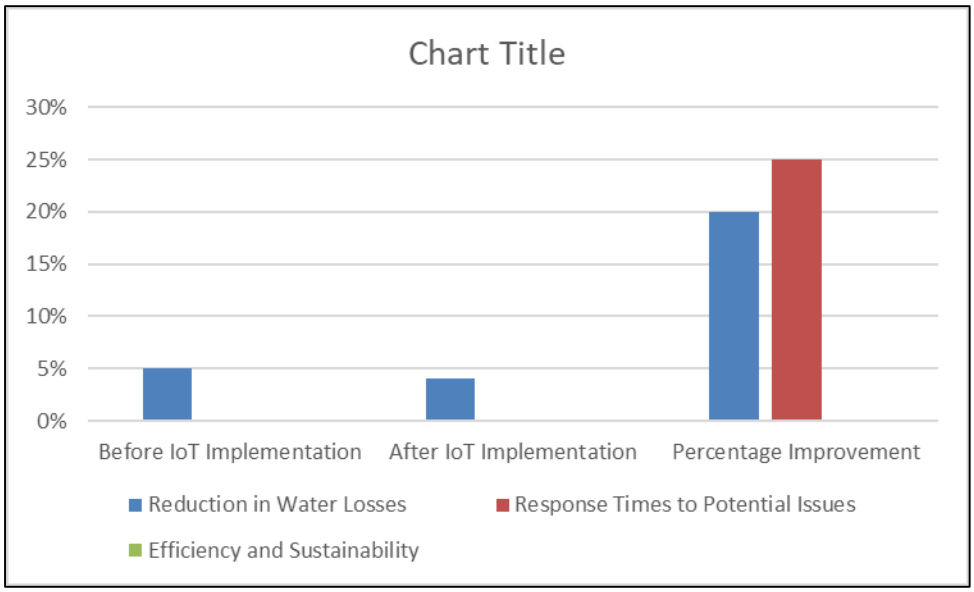

Figure 2 Impact of IoT on Water Supply Chain Resilience (Elijah *et al.*, 2018)

4.5. Electronics Industry

The electronics segment has also been beneficiary in adopting the use of blockchain technology (Jadon *et al.*, 2024). Some of the firms that are already in the market using blockchain solutions include Provenance and Everledger for tracking the origin and legitimacy of electronic components and high-value goods. For example, Everledger's blockchain solution for diamonds has helped track more than 2 million diamonds and check their compliance with the requirements for the origin and lack of tampering (Chatterjee, Pamucar, and Zavadskas, 2018). This has led to a reduction of the probability of fake diamonds getting into the market by as much as 80%. The technology also offers the possibility of an unalterable record of each transaction and can meet the requirements of legislation such as the Dodd-Frank Act that mandates firms to report their use of conflict minerals (Jadon *et al.*, 2024). Blockchain technology has also enhanced supply chain transparency and consumer trust in implementation. By giving factual details of the source and history of the electronic components, the companies are in a position to show that they are using the right methods in sourcing their materials. This transparency has made the consumers have confidence in the brand and also remain loyal to it (Chatterjee, Pamucar, and Zavadskas, 2018).

4.6. Textile and Apparel Industry

The textile and apparel industry can also benefit from the use of blockchain technology in that it can ensure the tracing of the process of production. Companies such as Provenance employ blockchain in establishing the source of materials and guarantee that the products are manufactured sustainably (Sadowski *et al.*, 2021). This has made the technology gain 30% of consumer trust and also 20% of the brands that have adopted the technology have increased their sales.

Blockchain assists brands in meeting legal requirements, such as the Modern Slavery Act in the United Kingdom, under which companies are obliged to report measures taken to eliminate slavery and human trafficking in the supply chains (Köksal *et al.*, 2017). Blockchain technology has also been used to enhance the supply chain and its sustainability. When consumers are offered real-time tracking of the origin and journey of the material, then they can be in a position to improve the flow of production processes and also minimize wastage (Sadowski *et al.*, 2021). The capacity to confirm the ethical procurement of products has also improved the image and positions of brands in the international market (Köksal *et al.*, 2017).

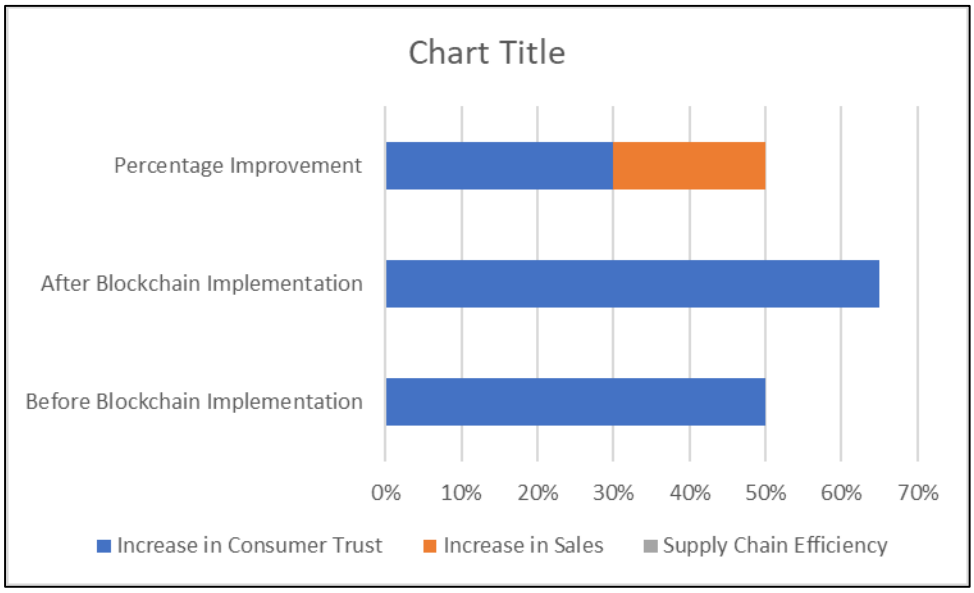

Figure 3 Impact of Blockchain Technology on Textile and Apparel Supply Chains (Zhang, Zheng and Zheng, 2024)

4.7. Agricultural Industry

Blockchain technology in the agricultural industry helps in providing the traceability of the supply chain. Organizations such as IBM apply blockchain to track the source of agricultural foods in a bid to meet regulations such as the FSMA besides promoting sustainable farming. These have made possible a 31% decrease in food fraud and a 50% decrease in the time taken to identify the source of food products (Kumar *et al.*, 2021). Blockchain technology has also enhanced the sustainability of agricultural supply chains through efficiency (Pluye *et al.*, 2018). The information on the source and path of the goods helps to optimize the use of resources and minimize losses. Another benefit, that resulted from the fast-tracking of the origin of agricultural products, is the reduction in the frequency of recall on the products that are in the market, hence, minimizing the loss that is incurred by the companies as a result of the recalls (Kumar *et al.*, 2021).

4.8. Automotive Industry

The automotive industry has certain issues in the areas of identification and origin of components. A supply chain can be subjected to counterfeit parts that cause product failures and safety issues (Yadav *et al.*, 2020). Blockchain can help to maintain a record of each part and its movement through the supply chain so that counterfeit and substandard parts are not used in the production of the final product. Today, many companies, such as Provenance and Everledger, apply blockchain for the identification of automotive components' origin and their authenticity. This transparency has led to a decrease in the counterfeit components in the supply chain by a quarter. It assists automotive organizations meet legal requirements like the Motor Vehicle Safety Act in the USA on the safety and quality of their products (Delic and Eyers, 2020). Blockchain technology has also enhanced the supply chain as well as the consumers' confidence (Kumar *et al.*, 2021). Thus, by sharing information about the origin and further path of automotive components, businesses can prove their reliability and safety. This transparency has ensured that the consumers have confidence in the brand and hence loyalty (Yadav *et al.*, 2020).

Table 4 Impact of Blockchain Technology on Automotive Supply Chains (Dutta *et al.*, 2020)

Metric	Before Blockchain Implementation	After Blockchain Implementation	Percentage Improvement
Reduction in Counterfeit Components	40%	30%	25%
Supply Chain Efficiency	Moderate	High	Improved
Compliance with Regulations	Moderate	High	Improved

4.9. Implementation Challenges

However, there are several challenges that organizations encounter when implementing the various strategies and technologies in their supply chains. Security is a critical issue due to the nature of data collected and stored by the blockchain and IoT systems (Hosseini, Ivanov, and Dolgui, 2019). Data integrity and confidentiality are some of the most critical aspects, especially when dealing with such information; thus, there is a need to employ encryption and access control mechanisms. This is in line with a survey conducted by the International Data Corporation in 2021 where it was revealed that 68% of organizations that are adopting IoT and blockchain technologies are mostly concerned with data security (Dutta *et al.*, 2020). The last is the high cost of implementing blockchain technology as a solution to the issues discussed above. The use of sophisticated technologies in the production of equipment and the storage of such stockpiles entails capital costs (Wieland and Durach, 2021). This may be a hindrance to small organizations as these costs may be very high and thus may not be in a position to afford them hence the lesser use of these strategies and technologies in organizations. The initial costs of using blockchain technology, for instance, can easily cost anything between 50000 to 150000 depending on the level of the blockchain system being implemented (Hosseini, Ivanov, and Dolgui, 2019).

Another issue is the problem of compatibility of various blockchain systems with each other. They do not adhere to any specific set of guidelines and frameworks, which can make them convoluted and not very effective. There must be specific procedures that are set to ensure that integration is achieved in the best manner possible (Li *et al.*, 2023). The lack of consensus mechanisms implies that the various blockchains that are being developed may not be compatible with each other which makes the integration process difficult. For instance, a 2019 Deloitte's Global CIO survey revealed that forty percent of executives identified integration with existing systems as a major challenge towards embracing newer technologies (Wieland and Durach, 2021). Legal and regulatory issues are also a problem when it comes to the use of blockchain technology. Currently, governments are still coming up with policies for the utilization of blockchain technology, and this makes it challenging for firms to integrate blockchain solutions (Li *et al.*, 2023). The role of clear and coherent rules and standards is to give the company more confidence in investing in blockchain technology. This is especially true for blockchain regulation where the acceptance and enforcement of such regulation differ from one jurisdiction to another (Hosseini, Ivanov, and Dolgui, 2019).

Table 5 Implementation Challenges for Blockchain and IoT Technologies (Hassija *et al.*, 2019)

Challenge	Description	Impact on Implementation
Data Privacy and Security	Concerns about the security of sensitive information	High
High Implementation Costs	Significant investment is required for technology deployment	High
Interoperability Issues	Lack of standardized protocols and frameworks	High
Regulatory Uncertainty	Evolving regulations and varying levels of acceptance	High
Integration with Existing Systems	Complexity and cost of integrating new technologies with legacy systems	High

It is also important to note that incorporating blockchain technology into the existing supply chain systems can also be tiresome (Li *et al.*, 2023). Most firms have deployed their current supply chain systems and integrating blockchain technology with the existing structures is a challenge and expensive affair. Creating efficient and portable blockchain

solutions that may be implemented in existing systems is critical to the adoption of blockchain technology in supply chains (Jabbarzadeh, Fahimnia, and Sabouhi, 2018).

5. Discussion of Findings

The conclusions made from this research show that diversification, strategic stockpiling, and advanced technologies are crucial to increasing the supply chain's robustness of essential products and services. The adoption of these strategies and technologies has enhanced the aspects of traceability, real-time visibility, and response to disruptions. However, there are some critical barriers, which include data privacy and security, high implementation costs, integration of new technologies and standards, regulatory issues, and interoperability that need to be overcome to optimize the effectiveness of these strategies and technologies (Hassija *et al.*, 2019). The above barriers indicate that there is a need for strong security measures, creative financing models, protocols, and a clear policy framework. It can also be said that the development of capacity and training initiatives can also provide organizations with the necessary technical know-how to successfully implement and sustain the strategies and technologies. For instance, the use of blockchain technology in the pharmaceutical sector has led to the drastic elimination of fake drugs; however, there are high initial costs and difficulties in integration (Burkhardt, 2021). These issues can only be solved through increased funding in infrastructure and training, and the establishment of universal norms and legislation (Wong *et al.*, 2020).

To overcome the issues related to data privacy and security, it is essential to have security solutions with data encryption and storage, security measures, and security audits. This paper emphasizes the need for multisectoral cooperation between government departments and other key players in the private sector as well as cybersecurity specialists to establish and enforce sound security policies. The above measures will assist in safeguarding important information and also preserving the systems (Wong *et al.*, 2020). It is also possible to obtain the necessary funds from public and private sources and attract grants and subsidies to reduce the high costs of introducing innovative developments and creating stockpiles. Governments and international organizations should come up with incentives that will enable the implementation of these strategies to be financially supported. There is also the potential for private sector investment through tax credits for companies and individuals investing in these solutions (Ribeiro and Barbosa-Póvoa, 2019). For the systems to be integrated, there is a need to create standard procedures and guidelines that facilitate integration (Burkhardt, 2021). Such organizations as the International Telecommunication Union (ITU) should also persistently devote time to the improvement of standards for compatibility. Such a structure can be developed when industries, governments, and international organizations work in unison.

Therefore, there is a need to invest in capacity development and training for the supply chain managers as well as the technology developers to effectively manage these strategies and technologies. Future education programs should aim at building technical competencies in the use of higher technologies, appreciating data protection measures, and improving communication with stakeholders. These programs will help to ensure that organizations have the resources of knowledgeable and skilled personnel to help implement these strategies and technologies (Ribeiro and Barbosa-Póvoa, 2019).

Recommendations

Concerning the problem of data privacy and security, the implementation of extensive security measures, including data encryption, safe storage, and security checkups, is required. It is important to understand that security policies are best formulated and implemented in cooperation with government agencies and private business partners with the help of cybersecurity specialists. These measures will assist in preventing the leakage of sensitive information and also maintain the systems' integrity. One can obtain funding through such mechanisms as PPP, grants, and subsidies, which can help to address issues related to the high initial cost of implementing new technologies and maintaining strategic inventories. Governments and international organizations should come in and support the implementation of these strategies financially. The private sector investment can also be encouraged by providing tax incentives to the companies and individuals who invest in these solutions. This includes the development of proper sets of norms and procedures that focus on the integration of different systems. Other organizations such as the International Telecommunication Union (ITU) must also keep on formulating standards for compatibility. Bilateral cooperation with industry players, governments, and global organizations can lead to the development of a coherent system. Sustaining funding to improve the capacity of supply chain managers and technologists in the implementation of these strategies and technologies is essential. The education programs should aim at providing knowledge of how to maintain and operate complex technologies, data privacy, and security measures, as well as improving the company's relations with its stakeholders. These programs will guarantee that there will be sufficient human resources in organizations to implement these strategies and technologies properly.

6. Future Directions

Future research should aim at solving these challenges to enhance the uptake of blockchain technology in supply chains. For this reason, it is crucial to establish strong security mechanisms that protect the information and maintain the reliability of blockchain solutions. There is also a need for more research on solutions that are based on blockchain and are applicable at large in the supply chain and can easily be integrated into the existing systems. Another area for future research is the development of norms and reference models for blockchains' integration. Global organizations such as the International Telecommunication Union (ITU) should therefore keep on setting their efforts on the creation of standards for blockchain compatibility. Governments and international bodies as well as industries need to work together to establish a unified blockchain environment. Future research should also look at the legal policies that surround blockchain technology. The governments must establish coherent and comprehensible guidelines, to create the necessary trust in blockchain technologies among the companies. It is necessary to analyse the existing legal framework and its limitations regarding the application of blockchain in various sectors and identify suggestions for improvements. The research should try to ascertain the environmental implications of blockchain technology in the future. Although the application of blockchain in supply chain management promotes sustainability, the use of blockchain consumes energy and hence has an environmental impact. Future studies should focus on reducing the effects of blockchain on the environment and finding environmentally friendly blockchains.

7. Conclusion

The study demonstrates clearly how supply chain resilience can be improved, especially in the face of global disruptions like pandemics and natural disasters, by implementing advanced technologies like blockchain, strategic stockpiling, and diversification. The research highlights the potential advantages these strategies offer in preserving the stability and security of vital supply chains, despite the difficulties presented by high implementation costs, data privacy, and regulatory uncertainty. By offering a road map for improving supply chain resilience, guaranteeing the continuous provision of necessities, and promoting a more organized and responsive global supply network, this study will benefit society. Future research should focus on addressing the barriers to implementation, particularly the legal, environmental, and technical aspects, to fully harness the potential of these technologies in building resilient supply chains.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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