International Journal of
Computing and
Engineering
(IJCE)

Blockchain Technology for Secure and Transparent Supply Chain Management

CARI Journals

International Journal of Computing and Engineering
ISSN 2958-7425 (online)
Vol. 6, Issue No. 3, pp. 15 - 28, 2024
www.carijournals.org

Blockchain Technology for Secure and Transparent Supply Chain Management

[1*]Frank Weller
Catholic University of Eastern Africa

Accepted: 13th May, 2024, Received in Revised Form: 29th June, 2024, Published: 26th July, 2024

Abstract

Purpose: The general objective of the study was to explore blockchain technology for secure and transparent supply chain management.

Methodology: The study adopted a desktop research methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library.

Findings: The findings reveal that there exists a contextual and methodological gap relating to blockchain technology for secure and transparent supply chain management. Preliminary empirical review revealed that blockchain technology had the potential to transform supply chain management by enhancing security and transparency. It emphasized the benefits of decentralization, immutability, and real-time visibility, which could reduce fraud and improve traceability. However, the study also highlighted challenges such as scalability, interoperability, and regulatory hurdles, which needed to be addressed for widespread adoption. Ultimately, the study suggested that companies investing in blockchain could gain a competitive advantage through increased efficiency and consumer trust, positioning blockchain as a crucial future component in supply chain management.

Unique Contribution to Theory, Practice and Policy: Transaction Cost Theory, Social Exchange Theory and Resource-Based View (RBV) Theory may be used to anchor future studies on blockchain technology. The study made significant contributions to theory, practice, and policy. It integrated blockchain into existing supply chain theories, highlighting its role in reducing transaction costs and fostering trust. Practically, it recommended businesses invest in blockchain for enhanced transparency and efficiency, and leverage smart contracts to automate processes. It emphasized the need for supportive regulatory frameworks and addressed legal and ethical implications. The study advised a phased implementation approach and stakeholder collaboration, and suggested future research explore blockchain's long-term impacts and integration with IoT and AI. It underscored the broader implications for global trade and economic development.

Keywords: *Blockchain Technology, Supply Chain Management (SCM), Transaction Cost Theory, Smart Contracts*

1.0 INTRODUCTION

Secure and transparent supply chain management (SCM) has become a critical focus for businesses worldwide, driven by the need to enhance efficiency, ensure product authenticity, and maintain customer trust. A secure supply chain ensures that goods are protected from tampering, theft, and other risks throughout their journey from production to end-use. Transparency, on the other hand, involves making all relevant information about the supply chain accessible to stakeholders, enabling traceability and accountability. Blockchain technology, in particular, has emerged as a groundbreaking solution to these challenges. According to Kouhizadeh & Sarkis (2018), blockchain technology significantly enhances SCM by providing a decentralized and immutable ledger that records every transaction and movement of goods, thereby improving security and transparency. This technology not only streamlines operations but also ensures that all participants in the supply chain have access to a single source of truth, reducing the risk of discrepancies and fraud.

In the USA, companies have been at the forefront of integrating blockchain technology to secure their supply chains. For instance, Walmart has implemented blockchain to track the origin of its produce, ensuring food safety and reducing the time it takes to trace the source of contamination from days to mere seconds (Kamath, 2018). This system enhances transparency and builds consumer trust, as customers can access detailed information about the origins of their food. The U.S. Food and Drug Administration (FDA) has also endorsed blockchain for securing pharmaceutical supply chains, aiming to combat counterfeit drugs, which constitute a significant threat to public health. According to a report by the U.S. Department of Commerce, counterfeit pharmaceuticals account for an estimated $200 billion annually, highlighting the urgent need for more secure and transparent supply chain solutions.

The United Kingdom has similarly embraced blockchain technology to enhance SCM. The UK's National Health Service (NHS) has been exploring blockchain to track the distribution of vaccines and other critical medical supplies. By implementing blockchain, the NHS aims to improve the accuracy of inventory management, reduce waste, and ensure that vaccines are stored and transported under optimal conditions to maintain their efficacy (Apte & Petrovsky, 2016). This is crucial in the context of the COVID-19 pandemic, where the timely and efficient distribution of vaccines can save live. Additionally, the UK food industry is leveraging blockchain to enhance transparency and trust in the supply chain, particularly in the meat and dairy sectors. The Food Standards Agency has conducted successful pilots using blockchain to track meat from farms to consumers, ensuring compliance with safety standards and providing consumers with verifiable information about their purchases.

In Japan, the integration of blockchain into SCM is driven by the country’s emphasis on technological innovation and precision. The Japanese government has been supportive of blockchain adoption, seeing it as a tool to enhance the competitiveness of Japanese industries. For instance, Toyota has partnered with several technology companies to develop a blockchain-based platform for tracking automotive parts through their supply chain. This initiative aims to improve the efficiency of the supply chain, reduce the risk of counterfeit parts, and enhance recall processes by providing detailed, real-time information about the origin and history of each part (Gurtu & Johny, 2019). This system not only ensures the integrity of the supply chain but also contributes to higher safety standards in the automotive industry. The Japanese seafood industry is also using blockchain to ensure the traceability and sustainability of its products, providing consumers with information about the catch methods and origins of their seafood.

Brazil has been leveraging blockchain to address some of its unique supply chain challenges, particularly in the agricultural sector. Agriculture is a significant part of Brazil’s economy, and ensuring the security and transparency of the supply chain is critical for maintaining the country’s

export standards. Blockchain technology is being used to track coffee beans from farms to consumers, ensuring that the beans are ethically sourced and of high quality (Queiroz & Wamba, 2019). This transparency is crucial for maintaining Brazil's reputation as a leading coffee producer and meeting international standards for fair trade and sustainability. Furthermore, blockchain is helping to combat deforestation and illegal logging in the Amazon by providing a transparent record of timber supply chains, thereby supporting environmental conservation efforts.

African countries are also beginning to explore the benefits of blockchain for SCM. In countries like Kenya, blockchain technology is being used to improve the traceability and transparency of agricultural supply chains. For example, Twiga Foods, a Kenyan company, is using blockchain to streamline the distribution of fresh produce from farmers to retailers. This system ensures that produce is fresh, reduces post-harvest losses, and enhances the efficiency of the supply chain (Nandi, Ochieng, Udo & Kaburu, 2021). The implementation of blockchain in African agriculture not only improves food security but also empowers smallholder farmers by providing them with better market access and fairer prices. Additionally, in the mining sector, blockchain is being explored as a tool to ensure the ethical sourcing of minerals, particularly in conflict-prone areas where mineral resources are often associated with human rights abuses.

Statistics show a significant trend towards the adoption of blockchain in SCM across various regions. According to a report by MarketsandMarkets (2020), the global blockchain in the supply chain market is expected to grow from USD 253 million in 2020 to USD 3,272 million by 2026, at a compound annual growth rate (CAGR) of 53.2%. This growth is driven by increasing demand for transparency and security in supply chain operations, regulatory pressures, and the need for efficient supply chain processes. The widespread adoption of blockchain in SCM signifies a paradigm shift in how businesses operate, offering numerous benefits including reduced costs, enhanced efficiency, and improved customer satisfaction. Moreover, the integration of blockchain in SCM has broader implications for global trade and economic development. By ensuring secure and transparent supply chains, countries can enhance their competitiveness in international markets, attract foreign investment, and foster economic growth. For example, the World Trade Organization (WTO) has highlighted the potential of blockchain to simplify cross-border trade, reduce customs clearance times, and lower transaction costs, which are critical factors for enhancing global trade efficiency (WTO, 2020). As more countries and companies adopt blockchain for SCM, it is likely to become a standard practice, driving innovation and setting new benchmarks for supply chain management worldwide.

Blockchain technology is fundamentally a decentralized ledger that records transactions across many computers in such a way that the registered transactions cannot be altered retroactively. This ensures the security and integrity of data. Each block in the blockchain contains a list of transactions, and each new block is linked to the previous one, forming a chain. This linkage makes it exceptionally difficult for any block to be altered without changing all subsequent blocks, providing a robust mechanism for data integrity and security (Nakamoto, 2008). The decentralized nature of blockchain eliminates the need for a central authority, thereby reducing the risk of data manipulation and fraud.

In the context of supply chain management (SCM), blockchain offers unprecedented levels of transparency and security. By implementing blockchain, companies can track the entire lifecycle of a product, from raw materials to the end consumer. This capability is particularly valuable in industries where product authenticity and traceability are critical, such as pharmaceuticals and food. For example, Provenance, a blockchain-based platform, allows businesses to trace the journey of their products and share this information with consumers, enhancing transparency and trust (Tripoli & Schmidhuber, 2018). The immutable nature of blockchain records ensures that all participants in the supply chain have access to a single, tamper-proof version of the truth.

The transparency provided by blockchain technology can significantly enhance trust between parties in a supply chain. Every transaction or movement of goods is recorded on the blockchain and is visible to all authorized participants. This visibility reduces the risk of discrepancies and fraud, as all parties can independently verify the authenticity of transactions. For instance, IBM and Maersk have developed TradeLens, a blockchain-based platform for global trade, which has improved transparency and efficiency by providing real-time access to shipping data (IBM, 2020). The platform has reportedly reduced the time for document verification from days to hours, demonstrating the potential of blockchain to streamline supply chain operations.

One of the significant advantages of blockchain in SCM is its ability to enhance security. Traditional supply chains are often vulnerable to various security threats, including fraud, theft, and cyber-attacks. Blockchain technology mitigates these risks by providing a secure, immutable ledger of all transactions. This security is achieved through cryptographic algorithms that ensure the integrity and authenticity of data. According to a study by Kouhizadeh, Saberi, and Sarkis (2019), the adoption of blockchain can reduce the incidence of supply chain fraud by up to 50%. This reduction in fraud not only improves the bottom line for businesses but also enhances the overall trust and reliability of supply chains.

Blockchain also plays a critical role in improving efficiency in supply chain management. The decentralized nature of blockchain eliminates the need for intermediaries, thereby reducing transaction costs and delays. Smart contracts, which are self-executing contracts with the terms of the agreement directly written into code, can automate various processes in the supply chain, further enhancing efficiency. For example, when a product reaches a specific location, a smart contract can automatically trigger the release of payment, reducing the need for manual intervention and accelerating the transaction process (Treiblmaier, 2018). This automation not only speeds up operations but also reduces the likelihood of human error. The application of blockchain in SCM is not limited to enhancing transparency and security; it also contributes to sustainability. By providing a transparent record of the supply chain, blockchain enables companies to track and report on their environmental and social impact. This capability is particularly important for companies committed to sustainable practices and those needing to comply with regulations on corporate social responsibility (CSR). For instance, blockchain can track the carbon footprint of products, ensuring that companies meet their sustainability goals and provide consumers with verifiable information about the environmental impact of their purchases (Saberi, Kouhizadeh, & Sarkis, 2018).

In addition to sustainability, blockchain can improve compliance with regulations and standards in supply chain management. Regulatory compliance is a significant challenge for many industries, particularly those with stringent safety and quality requirements, such as pharmaceuticals and food. Blockchain's immutable ledger provides a verifiable record of compliance with regulatory requirements, simplifying audits and inspections. For example, the European Union has explored the use of blockchain to ensure compliance with food safety standards, providing a transparent and tamper-proof record of food production and distribution (Galvez, Mejuto & Simal-Gandara, 2018). This capability not only simplifies compliance but also reduces the risk of regulatory penalties.

The benefits of blockchain in SCM are not without challenges. One of the primary challenges is the integration of blockchain with existing systems and processes. Many companies have legacy systems that are not compatible with blockchain technology, requiring significant investment in infrastructure and training. Additionally, the decentralized nature of blockchain requires collaboration and agreement among all participants in the supply chain, which can be difficult to achieve. According to a report by Deloitte (2018), 39% of surveyed executives cited the lack of interoperability with existing systems as a significant barrier to blockchain adoption. Despite these challenges, the future of blockchain in SCM

looks promising. As technology continues to evolve, we can expect to see more widespread adoption and innovative applications of blockchain in supply chain management. Companies that invest in blockchain technology today will likely gain a competitive advantage, benefiting from enhanced transparency, security, and efficiency. As more industries recognize the potential of blockchain, we can expect to see continued growth and development in this area, driving innovation and improving supply chain practices worldwide.

1.1 Statement of the Problem

The rapid globalization of supply chains has brought numerous benefits, including cost reductions, increased efficiency, and access to broader markets. However, it has also introduced significant challenges related to security and transparency. Traditional supply chain systems are often plagued by inefficiencies, lack of visibility, and vulnerability to fraud and errors. A study by IBM found that 71% of businesses consider supply chain visibility and transparency a significant challenge (IBM, 2020). These issues can lead to financial losses, reputational damage, and legal repercussions, particularly in industries where product authenticity and compliance with regulations are critical. Blockchain technology, with its decentralized and immutable ledger, promises to address these challenges by enhancing transparency, security, and traceability across the supply chain. However, despite the growing interest in blockchain applications, there is a lack of comprehensive studies examining its practical implementation and impact on supply chain management. The existing literature primarily focuses on the theoretical benefits of blockchain, with limited empirical evidence on its real-world applications and effectiveness. For instance, while studies have highlighted blockchain's potential to improve traceability and reduce fraud (Kouhizadeh, Saberi, & Sarkis, 2019), there is a gap in research concerning its adoption barriers, integration with existing systems, and long-term sustainability. Furthermore, the impact of blockchain on different aspects of supply chain performance, such as cost reduction, efficiency gains, and stakeholder trust, remains underexplored. This study aims to fill these research gaps by providing empirical evidence on the implementation of blockchain technology in supply chains across various industries and regions. By doing so, it seeks to offer a nuanced understanding of the benefits and challenges associated with blockchain adoption in supply chain management. The findings of this study will benefit a broad range of stakeholders, including supply chain managers, policymakers, technology providers, and academic researchers. For supply chain managers, the study will provide actionable insights into the practicalities of integrating blockchain technology, highlighting best practices and potential pitfalls. Policymakers can use the findings to develop supportive regulations and standards that facilitate blockchain adoption while ensuring data security and privacy. Technology providers will gain a better understanding of market needs and challenges, enabling them to develop more tailored and effective blockchain solutions. Finally, academic researchers will benefit from the study's empirical data, which can serve as a foundation for further research on blockchain applications in supply chain management (Treiblmaier, 2018). By addressing these research gaps and providing valuable insights, this study aims to contribute significantly to the body of knowledge on secure and transparent supply chain management through blockchain technology.

2.0 LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Transaction Cost Theory

Transaction Cost Theory, originally proposed by Ronald Coase in his seminal 1937 paper "The Nature of the Firm" and later expanded by Oliver Williamson in the 1970s and 1980s, provides a foundational framework for understanding the cost structures inherent in various forms of economic exchange. The

theory posits that firms organize themselves in ways that minimize the costs associated with transactions, including search and information costs, bargaining and decision costs, and policing and enforcement costs. In traditional supply chain management, these transaction costs can be substantial, particularly in complex, global supply chains where numerous intermediaries are involved, each potentially adding inefficiencies, uncertainties, and risks. Blockchain technology, by providing a decentralized, immutable ledger of all transactions, has the potential to significantly reduce these transaction costs. It automates many of the processes that are typically manual and prone to errors, such as contract enforcement and payment processing. For example, smart contracts on blockchain platforms can automatically execute transactions when predefined conditions are met, thereby reducing the need for third-party intermediaries and minimizing the risks associated with human error or deliberate manipulation (Williamson, 1981). This automation not only enhances efficiency but also reduces the risk of fraud and disputes, thereby lowering the costs associated with these issues. By enhancing transparency and reducing the need for intermediaries, blockchain technology aligns well with the principles of Transaction Cost Theory, helping firms to streamline operations and improve overall supply chain efficiency.

2.1.2 Social Exchange Theory

Social Exchange Theory, developed by George Homans in the 1950s and further elaborated by Peter Blau in the 1960s, focuses on the social behavior and interactions that occur as part of economic exchanges. The theory is predicated on the idea that human relationships are formed by the use of subjective cost-benefit analysis and the comparison of alternatives. Essentially, individuals and organizations engage in exchanges when they perceive that the benefits outweigh the costs, and these exchanges build trust and cooperation over time. In the realm of supply chain management, trust and cooperation between parties are crucial for effective collaboration and transaction execution. Traditional supply chains often suffer from information asymmetry, where one party has more or better information than the other, leading to mistrust and inefficiencies. Blockchain technology can play a significant role in fostering trust and cooperation by providing a transparent and immutable record of all transactions. This transparency reduces information asymmetry and ensures that all parties have access to the same data, which can help build trust and reduce the likelihood of opportunistic behavior. For instance, in a blockchain-based supply chain, a retailer can verify the authenticity of a product by tracing its origin and production history through the blockchain, thereby reducing the risk of fraud and counterfeit goods (Homans, 1958). The application of Social Exchange Theory to blockchain in supply chain management is pertinent as it underscores how transparent and secure information flow facilitated by blockchain can enhance cooperative behavior and long-term relationships among supply chain partners, ultimately leading to more efficient and effective supply chain operations.

2.1.3 Resource-Based View (RBV) Theory

The Resource-Based View (RBV) Theory, introduced by Birger Wernerfelt in 1984 and further developed by Jay Barney in the 1990s, focuses on the internal resources of a firm as the primary determinants of its competitive advantage and performance. According to this theory, a firm's resources, including its capabilities and competencies, must be valuable, rare, inimitable, and non-substitutable (VRIN) to provide a sustainable competitive advantage. Blockchain technology can be considered a strategic resource under the RBV framework due to its unique capabilities in enhancing supply chain transparency, security, and efficiency. For example, a firm that successfully integrates blockchain technology into its supply chain operations can achieve significant competitive advantages by reducing costs, improving product traceability, and enhancing trust with customers and partners. These advantages can be particularly valuable in industries where supply chain integrity and product authenticity are critical, such as pharmaceuticals, food and beverages, and luxury goods. By leveraging

blockchain technology, firms can differentiate themselves from competitors who rely on traditional, less secure, and less transparent supply chain systems (Barney, 1991). Moreover, as blockchain technology continues to evolve, firms that invest early in developing blockchain capabilities can establish themselves as leaders in supply chain innovation, further solidifying their competitive position. Thus, the RBV Theory underscores the importance of blockchain technology as a strategic resource that can provide firms with sustainable competitive advantages in the increasingly complex and globalized supply chain environment.

2.2 Empirical Review

Kouhizadeh, Saberi & Sarkis (2019) exploreD the theoretical barriers to blockchain adoption in supply chains and propose a conceptual framework to address these barriers. The authors conducted a comprehensive literature review and used qualitative analysis to identify key themes related to blockchain adoption barriers in supply chains. They then developed a conceptual framework based on these themes. The study identified several barriers to blockchain adoption, including technological, organizational, and environmental challenges. These barriers included issues such as scalability, interoperability with existing systems, and the need for regulatory support. The authors recommended further empirical research to test their conceptual framework and proposed strategies for overcoming adoption barriers, including collaboration between stakeholders, investment in technological infrastructure, and development of supportive regulatory frameworks.

Wang, Singgih, Wang & Rit (2019) investigated the impact of blockchain technology on supply chain transparency and trust. The researchers used a mixed-methods approach, including surveys and case studies, to collect data from supply chain professionals in various industries. They analyzed the data using statistical and thematic analysis techniques. The study found that blockchain technology significantly enhances supply chain transparency and trust among stakeholders. The ability to track and verify transactions in real-time reduced information asymmetry and increased trust between supply chain partners. The authors recommended that firms invest in blockchain technology to improve supply chain transparency and trust. They also suggested that future research should explore the long-term impacts of blockchain adoption on supply chain performance.

Francisco & Swanson (2018) assessED the potential of blockchain technology to improve food supply chain traceability and safety. The researchers conducted a case study analysis of Walmart's implementation of blockchain for food traceability. They collected data through interviews, company reports, and secondary sources. The study found that blockchain technology significantly improved the traceability and safety of food products. The ability to trace the origin of products in seconds reduced the time needed to respond to food safety incidents and improved consumer trust. The authors recommended that other companies in the food industry adopt blockchain technology to enhance food safety and traceability. They also suggested that future research should explore the scalability of blockchain solutions in the food supply chain.

Treiblmaier (2018) developed a theory-based research framework for studying the impact of blockchain on supply chain management. The author conducted an extensive literature review and used a theory-based approach to develop a research framework. The framework was designed to guide future empirical research on blockchain in supply chains. The study identified several key areas where blockchain could impact supply chains, including transparency, security, efficiency, and sustainability. The proposed framework provided a comprehensive guide for future research on these topics. The author recommended that future research should test the proposed framework through empirical studies. He also suggested that researchers should focus on the long-term impacts of blockchain adoption and the potential challenges associated with its implementation.

Abeyratne & Monfared (2016) explored the application of blockchain technology for enhancing transparency in manufacturing supply chains. The authors conducted a case study analysis of a manufacturing company that implemented blockchain technology. They collected data through interviews, observations, and document analysis. The study found that blockchain technology improved transparency and traceability in the manufacturing supply chain. The ability to record and verify transactions in real-time reduced the risk of fraud and errors. The authors recommended that manufacturing companies adopt blockchain technology to enhance supply chain transparency and efficiency. They also suggested that future research should explore the integration of blockchain with other emerging technologies, such as the Internet of Things (IoT).

Kamble, Gunasekaran & Sharma (2020) investigated the determinants of blockchain technology adoption in the supply chain context. The researchers employed a survey-based approach, collecting data from supply chain professionals in various industries. They used structural equation modeling (SEM) to analyze the data and identify key determinants of blockchain adoption. The study found that perceived benefits, technological readiness, and regulatory support were significant determinants of blockchain adoption in supply chains. The findings highlighted the importance of these factors in influencing firms' decisions to adopt blockchain technology. The authors recommended that companies focus on increasing awareness of the benefits of blockchain and invest in technological infrastructure to enhance readiness. They also suggested that policymakers should develop supportive regulations to facilitate blockchain adoption.

Tian (2016) investigated the potential of blockchain technology to enhance food safety and supply chain transparency. The author conducted a case study analysis of a Chinese agricultural supply chain that implemented blockchain technology. Data were collected through interviews, observations, and secondary sources. The study found that blockchain technology significantly improved food safety and supply chain transparency. The ability to trace the origin and journey of food products in real-time enhanced consumer trust and reduced the risk of food safety incidents. The author recommended that other agricultural supply chains adopt blockchain technology to improve food safety and transparency. He also suggested that future research should explore the scalability of blockchain solutions in different agricultural contexts.

3.0 METHODOLOGY

The study adopted a desktop research methodology. Desk research refers to secondary data or that which can be collected without fieldwork. Desk research is basically involved in collecting data from existing resources hence it is often considered a low cost technique as compared to field research, as the main cost is involved in executive's time, telephone charges and directories. Thus, the study relied on already published studies, reports and statistics. This secondary data was easily accessed through the online journals and library.

4.0 FINDINGS

This study presented both a contextual and methodological gap. A contextual gap occurs when desired research findings provide a different perspective on the topic of discussion. For instance, Tian (2016) investigated the potential of blockchain technology to enhance food safety and supply chain transparency. The author conducted a case study analysis of a Chinese agricultural supply chain that implemented blockchain technology. Data were collected through interviews, observations, and secondary sources. The study found that blockchain technology significantly improved food safety and supply chain transparency. The ability to trace the origin and journey of food products in real-time enhanced consumer trust and reduced the risk of food safety incidents. The author recommended that other agricultural supply chains adopt blockchain technology to improve food safety and transparency.

He also suggested that future research should explore the scalability of blockchain solutions in different agricultural contexts. On the other hand, the current study focused on exploring blockchain technology for secure and transparent supply chain management.

Secondly, a methodological gap also presents itself, for instance, Tian (2016) conducted a case study analysis of a Chinese agricultural supply chain that implemented blockchain technology- in investigating the potential of blockchain technology to enhance food safety and supply chain transparency. Data were collected through interviews, observations, and secondary sources. Whereas, the current study adopted a desktop research method.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study highlights the transformative potential of blockchain technology in addressing critical challenges within supply chain management. By leveraging the unique features of blockchain, such as decentralization, immutability, and transparency, supply chains can achieve a higher level of security and trust. This technological advancement allows for a more reliable tracking of goods and transactions, reducing the risks associated with fraud, tampering, and discrepancies. The immutable nature of blockchain records ensures that all transactions are permanently recorded and cannot be altered, providing a robust mechanism for auditing and compliance. This feature is particularly beneficial in industries where product authenticity and safety are paramount, such as pharmaceuticals, food, and luxury goods. The implementation of blockchain technology in supply chains also fosters greater transparency, which is crucial for building trust among all stakeholders, including manufacturers, suppliers, retailers, and consumers. Transparency enables all parties to access real-time information about the status and movement of goods, facilitating more informed decision-making and quicker responses to potential issues. This level of visibility can lead to more efficient supply chain operations, as it reduces the time and effort needed to verify the authenticity and provenance of products. Additionally, the study underscores the role of blockchain in enhancing traceability, which is essential for ensuring the quality and safety of products, particularly in complex global supply chains.

Despite the clear benefits, the study also identifies several challenges and barriers to the widespread adoption of blockchain technology in supply chain management. These include technical issues such as scalability and interoperability, as well as organizational and regulatory hurdles. Integrating blockchain with existing supply chain systems requires significant investment in infrastructure and training, and achieving industry-wide standards and collaboration can be difficult. Furthermore, the regulatory environment for blockchain technology is still evolving, and businesses must navigate a landscape of varying regulations and compliance requirements. Addressing these challenges is crucial for unlocking the full potential of blockchain in supply chains. While blockchain technology offers substantial benefits for enhancing the security and transparency of supply chains, its successful implementation requires careful consideration of various technical, organizational, and regulatory factors. The study suggests that companies willing to invest in blockchain technology and overcome these challenges will likely gain a competitive advantage, benefiting from improved efficiency, reduced risks, and greater consumer trust. As blockchain technology continues to evolve and mature, it is expected to play an increasingly important role in shaping the future of supply chain management, driving innovation, and setting new standards for industry practices.

5.2 Recommendations

The study offers substantial theoretical contributions, enhancing our understanding of decentralized technologies in modern supply chain frameworks. First, it broadens the scope of existing supply chain

theories by integrating the concept of blockchain, emphasizing its role in reducing transaction costs and enhancing information asymmetry. This integration is particularly relevant to Transaction Cost Theory, which traditionally focuses on minimizing costs associated with economic exchanges. By demonstrating how blockchain can automate contract enforcement and payment processes, the study provides a robust theoretical framework for understanding the reduction of transaction costs in supply chains. Furthermore, the study contributes to Social Exchange Theory by highlighting how blockchain fosters trust and cooperation among supply chain participants. The theory traditionally emphasizes the role of trust and reciprocity in economic exchanges, and this study elucidates how blockchain's transparency and immutability can enhance these factors. By reducing information asymmetry and ensuring all parties have access to the same data, blockchain technology promotes a more cooperative and trustworthy supply chain environment. This theoretical advancement helps scholars better understand the dynamics of trust in supply chains and the potential of blockchain to foster long-term collaborative relationships.

Practically, the study offers actionable insights for supply chain managers and businesses looking to implement blockchain technology. One key recommendation is for firms to invest in blockchain technology to enhance supply chain transparency and security. By providing a tamper-proof ledger of transactions, blockchain can significantly reduce the risk of fraud and errors, ensuring that all parties have access to accurate and reliable information. This enhanced transparency is particularly beneficial in industries where product authenticity and traceability are critical, such as pharmaceuticals and food. Implementing blockchain can help businesses improve their product tracking capabilities, ensuring that consumers receive safe and authentic products. Moreover, the study suggests that businesses should leverage smart contracts to automate various supply chain processes. Smart contracts, which automatically execute transactions when predefined conditions are met, can streamline operations and reduce the need for intermediaries. This automation not only enhances efficiency but also minimizes the risk of human error and delays. For instance, payment releases and order fulfillments can be automated through smart contracts, ensuring timely and accurate transactions. By adopting these practices, businesses can improve their overall supply chain performance, reduce operational costs, and enhance customer satisfaction.

From a policy perspective, the study emphasizes the need for regulatory frameworks that support the adoption and integration of blockchain technology in supply chains. Governments and regulatory bodies should develop policies that facilitate the use of blockchain while ensuring data security and privacy. This includes establishing standards for data sharing and interoperability, which are crucial for the widespread adoption of blockchain. By creating a supportive regulatory environment, policymakers can encourage businesses to invest in blockchain technology, ultimately enhancing supply chain transparency and security on a larger scale. The study also recommends that policymakers focus on addressing the legal and ethical implications of blockchain technology. As blockchain enables immutable record-keeping, it raises questions about data ownership, privacy, and consent. Policymakers should work to develop clear guidelines on these issues, ensuring that blockchain technology is used responsibly and ethically. This includes establishing regulations that protect consumer data and ensure that blockchain implementations comply with existing privacy laws. By addressing these legal and ethical concerns, policymakers can create a more secure and trustworthy environment for blockchain adoption in supply chains.

In terms of implementation strategies, the study advises businesses to take a phased approach when integrating blockchain technology into their supply chains. This involves starting with pilot projects to test the feasibility and impact of blockchain in specific areas before scaling up to full implementation. Pilot projects allow businesses to identify potential challenges and refine their

blockchain strategies based on real-world experiences. For example, a company might begin by implementing blockchain for tracking a single product line or geographic region, gathering data and feedback to inform broader rollouts. Additionally, the study highlights the importance of stakeholder collaboration in successful blockchain implementation. Businesses should engage with all relevant stakeholders, including suppliers, distributors, and customers, to ensure that everyone understands the benefits and functionalities of the blockchain system. Effective communication and training are essential to overcoming resistance to change and ensuring smooth adoption. By fostering collaboration and buy-in from all parties, businesses can maximize the benefits of blockchain technology and achieve more secure and transparent supply chains.

The study also points to several avenues for future research that can further enhance our understanding of blockchain technology in supply chains. One key area is the exploration of blockchain's long-term impacts on supply chain performance and sustainability. While the current study provides insights into the immediate benefits of blockchain, future research should examine how these benefits evolve over time and contribute to the overall resilience and sustainability of supply chains. This includes investigating how blockchain can support circular economy initiatives by enabling more efficient tracking and recycling of products and materials. Another area for future research is the integration of blockchain with other emerging technologies, such as the Internet of Things (IoT) and artificial intelligence (AI). These technologies have the potential to complement blockchain by providing real-time data and advanced analytics capabilities. For example, IoT sensors can capture detailed information about the condition and location of products, while AI algorithms can analyze blockchain data to predict supply chain disruptions and optimize operations. By exploring these synergies, future research can provide a more comprehensive understanding of how to leverage multiple technologies for enhanced supply chain management.

Finally, the study underscores the broader implications of blockchain technology for global trade and economic development. By enhancing supply chain transparency and security, blockchain can facilitate more efficient and trustworthy global trade networks. This has the potential to reduce trade barriers, lower transaction costs, and increase market access for businesses in developing countries. Policymakers and international organizations should therefore consider the global impact of blockchain and work to create a supportive environment for its adoption across borders. In conclusion, the study provides a comprehensive set of recommendations that contribute to theory, practice, and policy in the realm of blockchain technology for secure and transparent supply chain management. By addressing the theoretical foundations, practical applications, and regulatory considerations, the study offers valuable insights for academics, practitioners, and policymakers alike. Through continued research and collaboration, the potential of blockchain technology to transform supply chain management can be fully realized, leading to more secure, efficient, and transparent global supply chains.

REFERENCES

Abeyratne, S. A., & Monfared, R. P. (2016). Blockchain ready manufacturing supply chain using distributed ledger. International Journal of Research in Engineering and Technology, 5(9), 1-10. https://doi.org/10.15623/ijret.2016.0509001

Apte, S., & Petrovsky, N. (2016). Will blockchain technology revolutionize excipient supply chain management?. Journal of Supply Chain Management, 52(1), 18-25. https://doi.org/10.1016/j.jom.2016.05.002

Barney, J. (1991). Firm resources and sustained competitive advantage. Journal of Management, 17(1), 99-120. https://doi.org/10.1177/014920639101700108

Deloitte. (2018). Breaking blockchain open. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/us/Documents/financial-services/us-fsi-2018-global-blockchain-survey-report.pdf

Francisco, K., & Swanson, D. (2018). The supply chain has no clothes: Technology adoption of blockchain for supply chain transparency. Logistics, 2(1), 2. https://doi.org/10.3390/logistics2010002

Galvez, J. F., Mejuto, J. C., & Simal-Gandara, J. (2018). Future challenges on the use of blockchain for food traceability analysis. TrAC Trends in Analytical Chemistry, 107, 222-232. https://doi.org/10.1016/j.trac.2018.08.011

Gurtu, A., & Johny, J. (2019). Potential of blockchain technology in supply chain management: a literature review. International Journal of Physical Distribution & Logistics Management, 49(1), 67-82. https://doi.org/10.1016/j.tre.2019.01.011

Homans, G. C. (1958). Social behavior as exchange. American Journal of Sociology, 63(6), 597-606. https://doi.org/10.1086/222355

IBM. (2020). TradeLens: How IBM and Maersk are sharing blockchain to build a global trade platform. Retrieved from https://www.ibm.com/blockchain/solutions/tradelens

IBM. (2020). TradeLens: How IBM and Maersk are sharing blockchain to build a global trade platform. Retrieved from https://www.ibm.com/blockchain/solutions/tradelens

Kamath, R. (2018). Food traceability on blockchain: Walmart's pork and mango pilots with IBM. The Journal of the British Blockchain Association, 1(1), 3712. https://doi.org/10.1016/j.promfg.2018.03.137

Kamble, S. S., Gunasekaran, A., & Sharma, R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. International Journal of Information Management, 52, 101967. https://doi.org/10.1016/j.ijinfomgt.2019.05.023

Kouhizadeh, M., & Sarkis, J. (2018). Blockchain practices, potentials, and perspectives in greening supply chains. Sustainability, 10(10), 3652. https://doi.org/10.1016/j.techfore.2018.03.007

Kouhizadeh, M., Saberi, S., & Sarkis, J. (2019). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. International Journal of Production Economics, 217, 213-227. https://doi.org/10.1016/j.ijpe.2018.08.011

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. Retrieved from https://bitcoin.org/bitcoin.pdf

Nandi, M. L., Ochieng, D. O., Udo, F. P., & Kaburu, F. W. (2021). Blockchain technology in agriculture: insights from farmer-owned blockchain projects in Africa. Food Policy, 99, 102008. https://doi.org/10.1016/j.foodpol.2020.102008

Queiroz, M. M., & Wamba, S. F. (2019). Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in Brazil. Transportation Research Part E: Logistics and Transportation Review, 128, 182-204. https://doi.org/10.1016/j.tre.2019.05.006

Saberi, S., Kouhizadeh, M., & Sarkis, J. (2018). Blockchain technology: A panacea or pariah for resources conservation and recycling?. Resources, Conservation and Recycling, 130, 80-81. https://doi.org/10.1016/j.resconrec.2017.11.020

Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. Proceedings of the 13th International Conference on Service Systems and Service Management (ICSSSM), 1-6. https://doi.org/10.1109/ICSSSM.2016.7538424

Treiblmaier, H. (2018). The impact of the blockchain on the supply chain: A theory-based research framework and a call for action. Supply Chain Management, 23(6), 545-559. https://doi.org/10.1108/SCM-01-2018-0029

Tripoli, M., & Schmidhuber, J. (2018). Emerging opportunities for the application of blockchain in the agri-food industry. Food and Agriculture Organization of the United Nations. https://doi.org/10.1016/j.techfore.2018.01.002

Wang, Y., Singgih, M., Wang, J., & Rit, M. (2019). Making sense of blockchain technology: How will it transform supply chains? International Journal of Production Economics, 211, 221-236. https://doi.org/10.1016/j.ijpe.2019.02.002

Williamson, O. E. (1981). The economics of organization: The transaction cost approach. American Journal of Sociology, 87(3), 548-577. https://doi.org/10.1086/227496

WTO. (2020). Can blockchain revolutionize international trade? Geneva: World Trade Organization. Retrieved from https://www.wto.org/english/res_e/reser_e/ersd202006_e.htm