ISSN: 2455 - 1597

ijergs
Open Access

International Journal of Engineering Research and Generic Science (IJERGS)
Available online at: https://www.ijergs.in

Volume - 11, Issue - 3, May – June - 2025, Page No. 33 - 39

Blockchain Technology in Supply Chain Management: Innovations, Applications and Challenges

[1]Upasana Sharma, Research Scholar, Department of Computer Science, Arya College of Engineering, Jaipur.

[2]Tanu Sharma, Research Scholar, Department of Computer Science, Arya College of Engineering, Jaipur.

Abstract

This report provides a comprehensive analysis of the transformative potential of blockchain technology in supply chain management (SCM). It explores the key innovations driving its adoption, including integration with IoT and AI, advancements in blockchain platforms, enhanced security features, sophisticated smart contracts, the emergence of digital twins, and efficient consensus mechanisms. The report details diverse applications of blockchain across various industries such as food, pharmaceuticals, automotive, luxury goods, agriculture, and electronics, highlighting its role in enhancing transparency, traceability, efficiency, security, and cost reduction. Furthermore, it critically examines the challenges associated with blockchain implementation in SCM, including technological barriers, regulatory uncertainties, scalability issues, high implementation costs, and the necessity for stakeholder collaboration. Finally, the report outlines future trends and the anticipated evolution of blockchain in supply chain management, emphasizing increased adoption, convergence with other technologies, the development of industry standards, and a growing focus on sustainability and ethical sourcing.

Keywords: Blockchain Technology, SCM, Iot, Scalability Issue.

Introduction

Blockchain technology, at its core, represents a decentralized and distributed digital ledger that records transactions across numerous computers, ensuring transparency, immutability, and security. This fundamental architecture distinguishes it from traditional database systems, which rely on centralized control and are more susceptible to single points of failure and manipulation. The inherent characteristics of blockchain offer a robust solution for supply chain management (SCM), an intricate network involving multiple stakeholders and complex processes. The ability of blockchain to provide a secure and transparent record of transactions and the movement of goods addresses critical vulnerabilities prevalent in conventional SCM systems. Traditional approaches often suffer from a lack of a unified and verifiable source of information, leading to data inconsistencies, operational inefficiencies, and a lack of trust Modern supply chains are increasingly characterized by their complexity and global reach, involving numerous participants across diverse geographical locations. Existing management systems often struggle to effectively address the multifaceted challenges arising from this intricate ecosystem. Issues such as a lack of end-to-end visibility, operational inefficiencies, and susceptibility to disruptions are common pain points in traditional SCM. Furthermore, there is a growing demand from both consumers and businesses for greater transparency regarding the origins of products and the ethical considerations involved in their production. The integration of blockchain technology into supply chain management presents a significant opportunity to overcome these limitations and revolutionize how goods and information are managed across global networks. The global blockchain supply chain market has witnessed substantial growth, estimated at USD 2.26 billion in 2023, with projections indicating a remarkable compound annual growth rate (CAGR) of 90.2%

from 2024 to 2030. This significant market expansion reflects a growing recognition of blockchain's potential to address critical challenges and deliver tangible benefits in supply chain operations.9This report aims to provide a comprehensive analysis of the innovations driving the adoption of blockchain technology in supply chain management, explore its diverse applications across various industries, and critically examine the challenges associated with its implementation. The scope of this report encompasses global supply chains, with a particular emphasis on recent advancements and anticipated future trends up to the year 2025.

Innovations Driving Blockchain Adoption in Supply Chain

The integration of blockchain technology into supply chain management is being propelled by several key innovations that enhance its capabilities and address the evolving needs of modern logistics and commerce. One of the most transformative trends is the synergistic integration of blockchain with the Internet of Things (IoT) and Artificial Intelligence (AI). The combination of these technologies is creating "smart" and increasingly autonomous supply chain ecosystems. IoT devices, such as smart sensors and RFID tags, play a crucial role in collecting real-time data regarding the location, condition (including temperature and humidity), and movement of goods throughout the supply chain. This data, captured at various stages, is then securely recorded on the blockchain, ensuring its integrity and immutability. Furthermore, Artificial Intelligence (AI) and machine learning algorithms are being increasingly employed to analyze the vast amounts of data stored on the blockchain. This analysis enables businesses to optimize transportation routes, more accurately predict demand fluctuations, detect anomalies that might indicate inefficiencies or fraud, and ultimately make more informed and proactive decisions across their supply chain operations. For instance, blockchain-connected scanners, capable of reading barcodes and RFID tags, transmit scanned information directly to the blockchain, providing precise and real-time tracking of an item's journey. The synergy of these technologies fosters a more responsive, efficient, and transparent supply chain ecosystem, where data integrity is assured, and processes are increasingly automated.

Significant advancements in blockchain platforms are also driving adoption in SCM. Notably, the emergence and growing popularity of hybrid and consortium blockchains are addressing key enterprise concerns. These platforms offer a compelling balance between the complete transparency of public blockchains and the enhanced privacy and control afforded by private blockchains. Hybrid models allow organizations to leverage the benefits of both types, while consortium blockchains enable a group of organizations to collectively manage a network, establishing shared control and governance. This evolution is particularly beneficial for enterprise adoption as businesses often handle sensitive data that necessitates controlled access and customizable permissions. Platforms such as Hyperledger Fabric, Ethereum, Polygon, and Kaleido are prominent examples, offering distinct features and functionalities tailored for various SCM use cases. For example, the IBM Food Trust, built on Hyperledger Fabric, is widely used for enhancing traceability in the food industry. Kaleido, on the other hand, provides blockchain-as-a-service (BaaS) solutions, simplifying the deployment and management of blockchain networks for supply chain applications. The development of these more adaptable and enterprise- focused blockchain platforms is crucial for facilitating wider industrial integration.

Continuous enhancements in security features are also paramount for building trust and promoting the broader application of blockchain in supply chain management. Advancements in cryptography, including sophisticated encryption techniques and digital signatures, are bolstering the security of blockchain- based solutions, effectively preventing fraud, tampering, and unauthorized access to sensitive supply chain data. The use of permissioned blockchains further enhances security by ensuring that only authorized participants can access and modify data within the network, fostering a higher degree of trust among supply chain partners. These continuous improvements in security protocols are vital for building confidence in blockchain technology and encouraging its adoption across industries dealing with valuable and sensitive goods.

The growing sophistication of smart contracts is another crucial innovation driving blockchain adoption in SCM.[1] These self-executing contracts automate transactions and enforce agreements based on predefined conditions, significantly reducing the need for intermediaries and streamlining various processes. Applications of smart contracts in SCM include automated payments upon verification of delivery, automated processing of orders, and automated checks for regulatory compliance. As the technology evolves, smart contracts are becoming increasingly capable of handling complex business logic and workflows, moving beyond basic transactions to facilitate more sophisticated automation across the supply chain

The emergence of digital twins also represents a significant innovation at the intersection of blockchain and SCM. Digital twins are virtual replicas of physical supply chain operations, allowing organizations to simulate various scenarios and proactively mitigate potential risks. Blockchain technology enhances the functionality of digital twins by providing a secure and transparent record of the underlying data.[45] This ensures the accuracy and reliability of the simulations and predictions generated by the digital twins, offering a trusted and auditable foundation for risk management and strategic decision- making in supply chains.

Finally, the development of more efficient consensus mechanisms is addressing some of the historical limitations of blockchain technology in SCM. Traditional mechanisms like Proof-of-Work (PoW) have faced criticism for their energy consumption and scalability challenges. The emergence of more efficient algorithms, such as Proof-of-Stake (PoS) and Proof-of-Authority (PoA), offers more sustainable and scalable solutions for SCM applications. For instance, Ethereum's transition to PoS significantly reduced its energy consumption. These advancements are crucial for enabling the deployment of blockchain in large-scale supply chain networks with high transaction volumes and growing concerns about environmental sustainability.

Diverse Applications of Blockchain Across Industries

Blockchain technology is finding diverse and impactful applications across a wide range of industries, revolutionizing how supply chains are managed and optimized. One of the most prominent applications is in **enhancing transparency and traceability** throughout the supply chain. By providing an immutable and distributed record of product journeys, blockchain enables businesses and consumers to track goods from their point of origin to the final destination. This capability is crucial for verifying the authenticity of products, ensuring ethical sourcing

of materials, and facilitating swift and accurate product recalls when necessary.[1] For instance, Walmart's Food Trust network utilizes blockchain to track produce and pork products, enabling rapid identification of contamination sources. Similarly, De Beers leverages blockchain to trace the origin of diamonds, ensuring they are ethically sourced and conflict-free.

Blockchain also significantly contributes to **improved efficiency and cost reduction** in supply chain operations.[1] By streamlining processes, reducing the need for extensive paperwork, eliminating intermediaries, and automating transactions through smart contracts, blockchain helps organizations achieve substantial cost savings and enhance their operational efficiency. Studies indicate that blockchain technology has the potential to reduce supply chain-related costs by approximately 20%.[8] Maersk's collaboration with IBM to develop blockchain applications for freight tracking and administration exemplifies this, aiming to increase transparency, decrease idle time, and reduce overall costs in shipping and logistics.

The inherent security features of blockchain technology contribute to **stronger security and fraud prevention** within supply chains. The tamper-proof nature of blockchain records makes it exceptionally difficult to alter data, thereby mitigating the risk of fraud and ensuring the integrity of information across the supply chain.

This is particularly valuable in combating counterfeit products, as demonstrated by Chronicled's use of blockchain to verify the authenticity of pharmaceuticals. In the **food industry**, blockchain enables end-to-end traceability, ensuring food safety and quality from farm to consumer, as seen in the initiatives by Walmart, Nestlé, and Carrefour. The pharmaceutical industry utilizes blockchain to combat counterfeit drugs, enhance supply chain integrity, and ensure the authenticity of medications, with examples like MediLedger and initiatives by Pfizer and Merck. The automotive industry leverages blockchain for tracking components, managing vehicle history, and ensuring transparency across the supply chain, as demonstrated by BMW, Ford, and Volkswagen. In the luxury goods sector, blockchain is used for authenticating products and tracking their provenance, with notable examples including initiatives by LVMH, Prada, Cartier, and De Beers. The agriculture industry benefits from blockchain through enhanced transparency, fair compensation for farmers, tracking of organic status, and improved food safety, as seen in the applications by AgriDigital and Ripe.io. Finally, in the electronics industry, blockchain is being explored for combating counterfeit components and improving overall supply chain visibility, with initiatives by companies like Infineon and the Mobility Open Blockchain Initiative (MOBI).1

Navigating the Challenges of Blockchain Implementation in Supply Chain

Despite the numerous innovations and applications, the widespread implementation of blockchain technology in supply chain management is not without significant challenges. One of the primary hurdles is the technological barrier associated with integrating blockchain into existing legacy systems. Many organizations rely on established, often outdated, IT infrastructure that may not be readily compatible with blockchain technology. Ensuring seamless interoperability between different blockchain platforms and these existing systems is a complex and resource-intensive task. Furthermore, maintaining data quality and establishing robust data governance protocols on a

distributed ledger present additional complexities.[4] Ensuring the accuracy of data inputted into the blockchain and maintaining its consistency across the network are critical for the reliability of blockchain- based SCM solutions.

Regulatory and legal uncertainties also pose a significant challenge to the widespread adoption of blockchain in supply chain management. The legal landscape surrounding blockchain technology is still in its nascent stages, with a lack of clear and consistent legal frameworks and standards governing its application in SCM.[3] Issues related to data privacy regulations, such as the General Data Protection Regulation (GDPR), cross-border transactions, and overall compliance with existing laws add further complexity for businesses seeking to implement blockchain solutions.

Scalability issues represent another significant challenge, particularly for large-scale global supply chains that involve high transaction volumes and massive amounts of data.[1] The current blockchain infrastructure may struggle to efficiently process and store the sheer volume of transactions generated by complex supply chain networks, potentially leading to delays and increased costs. Ongoing research and development efforts are focused on addressing these limitations through various scaling solutions, such as sharding and Layer- 2 protocols.

The high implementation costs associated with blockchain technology can also be a substantial barrier to adoption. These costs include the initial investment in infrastructure setup, software development, the hiring of specialized blockchain expertise, and the ongoing maintenance of the network. Such significant financial outlays can be particularly challenging for small and medium-sized enterprises (SMEs) with limited budgets.

Finally, the successful implementation of blockchain in SCM necessitates extensive stakeholder collaboration and the establishment of trust among all participants in the supply chain. Convincing diverse organizations with potentially competing interests to actively participate and share data on a common platform can be a complex undertaking. Establishing clear governance models and addressing concerns around data privacy are crucial for fostering the necessary trust and encouraging widespread participation.

The Future Landscape: Trends and Evolution of Blockchain in Supply Chain

The future of blockchain technology in supply chain management appears promising, with several key trends indicating its continued evolution and increasing impact across industries.

Increased adoption across various sectors is a strong indication of blockchain's future trajectory in SCM.1 Market forecasts predict substantial growth in the blockchain supply chain market size, indicating a strong belief in its transformative potential.

The convergence of blockchain with other emerging technologies like IoT, AI, digital twins, and 5G is expected to create even more sophisticated and efficient SCM solutions. Efforts are also underway to develop industry standards and best practices for blockchain implementation in SCM. Initiatives like the Mobility Open Blockchain Initiative (MOBI) in the automotive sector aim to foster collaboration and establish common protocols. Finally, there is a growing focus on leveraging blockchain to enhance sustainability and ensure ethical sourcing practices throughout supply chains. Initiatives like Unilever's pilot project for tracing sustainable palm oil highlight this trend.

Conclusion

Blockchain technology is rapidly evolving and demonstrating its potential to revolutionize supply chain management. Innovations in areas such as IoT and AI integration, blockchain platform development, security enhancements, smart contract capabilities, digital twins, and consensus mechanisms are continuously expanding the possibilities for its application in SCM. These advancements are driving diverse applications across industries, from enhancing transparency and traceability to improving efficiency, reducing costs, and strengthening security. The ability of blockchain to provide an immutable and distributed ledger is proving invaluable in addressing the complexities and challenges of modern global supply chains. Despite its transformative potential, the widespread adoption of blockchain in SCM is still subject to several significant challenges, including technological barriers related to integration and interoperability, regulatory and legal uncertainties, scalability limitations, high implementation costs, and the critical need for stakeholder collaboration and trust. Overcoming these hurdles will be crucial for realizing the full benefits of blockchain technology in this domain. Looking ahead, the future landscape of blockchain in supply chain management is characterized by promising trends. Increased adoption across various industries, the convergence with other emerging technologies, the development of industry standards, and a growing focus on sustainability and ethical sourcing all point towards a significant and lasting impact. As the technology matures and these challenges are addressed, blockchain is poised to become a fundamental backbone for more efficient, transparent, and resilient global trade networks.

References

1. Attaran, M. Digital Technology Enablers and Their Implications for Supply Chain Management. Supply Chain Forum 2020, 21, 158–172.

2. Cooper, M.C.; Lambert, D.M.; Pagh, J.D. Supply Chain Management: More than a New Name for Logistics. Int. J. Logist. Manag. 1997, 8, 1–14.

3. Robertson, P.W.; Gibson, P.R.; Flanagan, J.T. Strategic Supply Chain Development by Integration of Key Global Logistical Process Linkages. Int. J. Prod. Res. 2002, 40, 4021–4040.

4. Bode, C.; Wagner, S.M. Structural Drivers of Upstream Supply Chain Complexity and the Frequency of Supply Chain Disruptions. J. Oper. Manag. 2015, 36, 215–228.

5. Manupati, V.K.; Schoenherr, T.; Ramkumar, M.; Wagner, S.M.; Pabba, S.K.; Singh, R.I.R. A Blockchain-Based Approach for a Multi-Echelon Sustainable Supply Chain. Int. J. Prod. Res. 2020, 58, 2222–2241.

6. Saberi, S.; Kouhizadeh, M.; Sarkis, J.; Shen, L. Blockchain Technology and Its Relationships to Sustainable Supply Chain Management. Int. J. Prod. Res. 2019, 57, 2117–2135.

7. Treiblmaier, H. Combining Blockchain Technology and the Physical Internet to Achieve Triple Bottom Line Sustainability: A Comprehensive Research Agenda for Modern Logistics and Supply Chain Management. Logistics 2019, 3, 10.

8. Choi, T.-M.; Feng, L.; Li, R. Information Disclosure Structure in Supply Chains with Rental Service Platforms in the Blockchain Technology Era. Int. J. Prod. Econ. 2020, 221, 107473.

9. Hald, K.S.; Kinra, A. How the Blockchain Enables and Constrains Supply Chain Performance. Int. J. Phys. Distrib. Logist. Manag. 2019, 49, 376–397.

10. Tehrani, M.; Gupta, S.M. Designing a Sustainable Green Closed-Loop Supply Chain under Uncertainty and Various Capacity Levels. Logistics 2021, 5, 20.

11. Bettis, R.A.; Mahajan, V. Risk/Return Performance of Diversified Firms. Manag. Sci. 1985, 31, 785–799.

12. Kshetri, N. 1 Blockchain's Roles in Meeting Key Supply Chain Management Objectives. Int. J. Inf. Manag. 2018, 39, 80–89.

13. Baralla, G.; Pinna, A.; Corrias, G. Ensure Traceability in European Food Supply Chain by Using a Blockchain System. In Proceedings of the 2019 IEEE/ACM 2nd International Workshop on Emerging Trends in Software Engineering for Blockchain, WETSEB, Montreal, QC, Canada, 27 May 2019; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2019; pp. 40–47.

14. Kuhi, K.; Kaare, K.; Koppel, O. Ensuring Performance Measurement Integrity in Logistics Using Blockchain. In Proceedings of the 2018 IEEE International Conference on Service Operations and Logistics, and Informatics, SOLI, Singapore, 31 July–2 August 2018; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2018; pp. 256–261.

15. Barua, A.; Konana, P.; Whinston, A.B.; Yin, F. An Empirical Investigation of Net-Enabled Business Value. MIS Q. 2004, 28, 585–620.

16. Gartner, 2017 Gartner Says Supply Chain Management Market Will Exceed $13 Billion in 2017, Up 11 Percent from 2016.

17. Rai, A.; Patnayakuni, R.; Seth, N. Firm Performance Impacts of Digitally Enabled Supply Chain Integration Capabilities. MIS Q. 2006, 30, 225–246.

18. Rai, A.; Brown, P.; Tang, X. Organizational Assimilation of Electronic Procurement Innovations. J. Manag. Inf. Syst. 2009, 26, 257–296.

19. Dasaklis, T.; Casino, F. Improving Vendor-Managed Inventory Strategy Based on Internet of Things (IoT) Applications and Blockchain Technology. In Proceedings of the IEEE International Conference on Blockchain and Cryptocurrency, ICBC, Seoul, Korea, 14–17 May 2019; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2019; pp. 50–55.

20. Dasaklis, T.K.; Casino, F.; Patsakis, C.; Douligeris, C. A Framework for Supply Chain Traceability Based on Blockchain Tokens. Lect. Notes Bus. Inf. Process. LNBIP 2019, 362, 704–716.