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REVIEW ARTICLE

UNLOCKING THE POTENTIAL OF BLOCKCHAIN IN SUPPLY CHAIN MANAGEMENT: APPLICATIONS AND CHALLENGES

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ABSTRACT

Blockchain technology is rapidly becoming one of the most groundbreaking technologies for revolutionizing supply chain management with unprecedented security, transparency, and efficiency. This paper presents a comprehensive literature review of blockchain and its applications in leading industries such as transportation, manufacturing, food and beverage, and healthcare. Blockchain applies distributed ledger technology to secure tamper-evident record-keeping, which significantly enhances traceability and provenance verification across complex supply chains. By integrating smart contracts, IoT connectivity, and decentralized financial services, blockchain can solve significant challenges, such as counterfeiting, supplier management, and enforcing sustainable and responsible sourcing practices. Despite these benefits, the mass-scale adoption of blockchain faces serious challenges, such as scalability, interoperability, regulatory ambiguity, and a lack of standardized frameworks. The report also addresses the environmental concerns of blockchain's power-intensive proof-of-work algorithm and discusses ways to counteract them. Future developments in artificial intelligence and 5G networks will continue to evolve supply chain management in ways that unleash unmatched efficiency and potential.

KEYWORDS

Supply chain management, Blockchain Technology, Supply Chain Transparency, Smart Contracts

1. INTRODUCTION

Blockchain technology functions as both a secure ledger system and a decentralized data store. It is a chain of blocks in linear progression, each containing a record of confirmed transactions. A block is appended to the existing chain when it is completed, forming an irreversible and tamper-proof record of all transactions. As each new block is appended, the distributed database is updated across the network to enable the secure transfer of digital assets, such as money, property, and contracts. In essence, blockchain is an Internet protocol that enables transparent and trustless transactions. This technology is ushering in a new era in the digital economy, characterized by decentralized asset control, digital currencies, and smart contracts (Kumar et al., 2025). The application of blockchain extends across a broad spectrum of domains, including healthcare, finance, energy, and public administration, and is an area of interest in both academic research and industry. In healthcare, for example, blockchain enables the offering of a secure infrastructure for storing and transmitting patient information, preserving confidentiality, and ensuring data integrity between authorized practitioners. Similarly, in finance, blockchain provides increased security and transparency for various digital financial instruments (Kumar et al., 2025; Abou Jaoude and Saade, 2019). Consequently, many organizations are closely observing how blockchain can be incorporated into their operations to enhance efficiency, security, and competitiveness. Innovation in blockchain technology will ensure its adoption in an even broader spectrum of industries. Its

potential to securely store and manage data in a transparent and immutable manner makes it a fundamental technology of the digital era. In the future, blockchain can be expected to play a key role in revolutionizing current systems into more secure, transparent, and decentralized alternatives (Aslam et al., 2021). The introduction of blockchain has transformed conventional financial frameworks, enabling innovations such as decentralized remittances, smart contracts that automate payments, and new asset classes, including cryptocurrencies (Burgess et al., 2022). In supply chain management, the use of blockchain offers immense benefits in terms of traceability and transparency. With tamper-proof records of transactions and asset movement, it enables real-time tracking of goods, mitigates counterfeiting risks, and enhances supply chain efficiency (Xu et al., 2023). In healthcare, blockchain is driving innovations in electronic health record management, clinical trial data management and pharmaceutical supply chain logistics. Patients have greater control over their personal health data, and researchers have access to more precise and interoperable datasets. Beyond healthcare, blockchain is revolutionizing the energy sector, particularly in use cases such as peer-to-peer energy trading, carbon credit markets, and decentralized grid management. By facilitating peer-to-peer transactions among energy consumers and producers, blockchain-based platforms promote the consumption of renewable energy, reduce reliance on centralized utilities, and assist in reducing costs. (Figure 1) the interaction and decision-making processes of the key stakeholders, consumers, producers, and

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policyholders. The green and yellow flags in the figure represent different decision agents for each actor (Chuan et al., 2024).

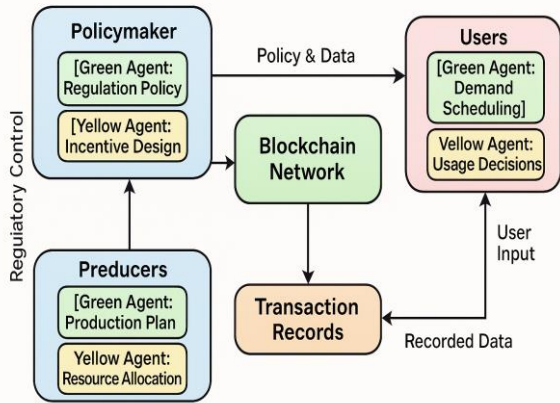


Figure 1: Decision making and interaction framework in a blockchain based system

1.2 Types Of Blockchains

Blockchains are typically categorized into three main types: public, private, and consortium (or federated). They have various characteristics, use cases, and governance models, and are therefore suitable for a variety of purposes. Public blockchains are decentralized and open to anyone who wishes to participate, such as Bitcoin and Ethereum (Desai et al., 2019). These blockchains are very transparent and immutable but are prone to scalability issues due to consensus algorithms such as Proof of Work or Proof of Stake. Private blockchains are permissioned blockchains that are controlled by a single organization (Lotfi et al., 2022). These offer greater control, increased transaction speed, and better data privacy; hence, they are suitable for enterprise and internal use cases. However, they compromise on decentralization and trustless interactions. Consortium blockchains are a middle ground, where the network is operated in collaboration with multiple organizations (Lotfi et al., 2022). These types of blockchains balance decentralization and efficiency and find applications in supply chain, banking, and multi-party collaboration use cases. Knowing these types is important for designing and implementing blockchain systems based on specific regulatory, operational, and trust requirements.

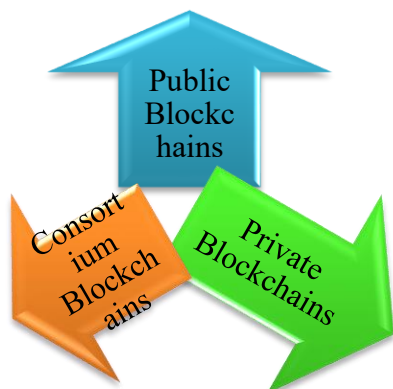


Figure 2: Types of blockchains

This study explores the diverse applications of blockchain technology across multiple industries, highlighting its advantages, limitations, and avenues for future development. The primary contributions of this study are outlined as follows: (i) Sectoral Insights – This study investigates the implementation of blockchain in key areas such as supply chain management, healthcare, finance, real estate, and the Internet of Things (IoT). (ii) Blockchain Classification of Blockchain systems are categorized into public, private, consortium, and hybrid models, providing a comparative overview. (iii) Technological Advancements – This discusses emerging innovations, including smart contracts, decentralized identity frameworks, and blockchain systems enhanced with artificial intelligence. (iv) Key Challenges and Remedies – This addresses critical issues such as scalability limitations, lack of interoperability, regulatory constraints, and high energy

consumption, and proposes optimized algorithms and policy-based interventions to mitigate them. (v) Vision for the Future – It sheds light on future trends, such as the role of blockchain in 6G network security, integration with decentralized AI models, and environmentally sustainable blockchain adoption. The remainder of this paper is organized as follows: Section 2 provides a detailed overview of blockchain applications across industries. Section 3 delves into the technical methodologies employed in these sectors. Section 4 offers a comprehensive discussion and analysis of the results. Finally, Section 5 concludes the study and outlines the potential future research directions.

2. APPLICATIONS OF BLOCKCHAIN TECHNOLOGY IN VARIOUS INDUSTRIES

Blockchain technology has found widespread use across various industries, spurring innovation in system design and real-world usage. In the banking and finance sectors, blockchain makes cross-border transactions easy and assists in the use of smart contracts, maximizing operational efficiency and significantly reducing transaction time (Lotfi et al., 2021). In medicine, blockchain offers secure electronic health record management and maximizes the authenticity of clinical trials by rendering data transparent and traceable, ultimately guaranteeing the accuracy of the findings (Perera et al., 2020). Blockchain is used in the real estate market to securely store property titles and assets that can be tokenized so that a property can be fractionally owned, and property transactions are simplified (Das et al., 2022). The healthcare industry also benefits from the power of blockchain in guaranteeing the reproducibility and integrity of clinical trial data to provide confident research findings (McGhin et al., 2019). In the field of intellectual property, blockchain offers secure digital rights management features, safeguarding rightful ownership, defending against fraudulent use, and ensuring fair compensation to content creators, thereby cultivating a just ecosystem. Blockchain is applied in the entertainment and gaming sectors through smart contracts to address royalties and income distribution fairly (Gürkaynak et al., 2018). It also enables players to own in-game assets, where they can be exchanged without dependency on centralized platforms. From the perspective of voting and governance, blockchain offers decentralized decision-making processes that increase transparency and accountability in the system (Subramanian, 2017). Blockchain provides secure and verifiable voting systems that eliminate fraud and ensure integrity. The benefits also extend to supply chains, such that blockchain allows traceability and confidence in the production and distribution chains (Lee and Pilkington, 2017). The adoption of blockchain across these diverse domains continues to grow at a rapid pace, reflecting its revolutionary ability to reshape digital trust and operational efficiency (Figure 3).

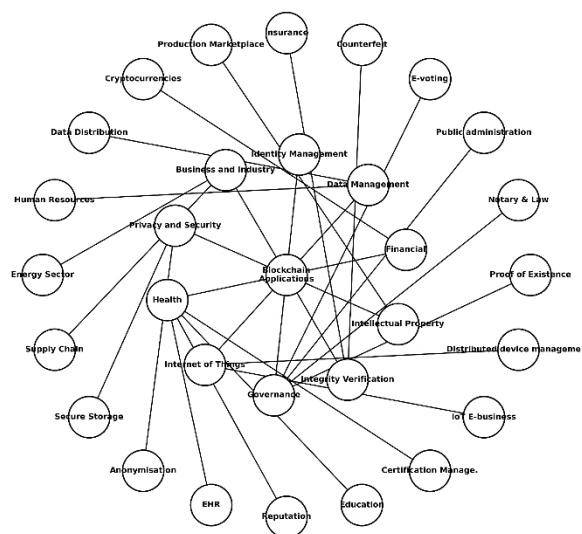


Figure 3: Blockchain technology application

2.1. Blockchain Techniques in Supply Chain Management

Blockchain technology has emerged as a groundbreaking development in supply chain management, enabling improved traceability, security, and operational efficiency (Khaqqi et al.,

2018). Its decentralized and tamper-proof ledger allows all transactions and movements of goods to be recorded transparently, thereby enhancing trust among stakeholders (Egelund et al., 2017). A key benefit is in supply chain finance, where the blockchain streamlines payment processes and ensures secure, real-time transactions between parties. It also facilitates compliance and auditing by securely recording regulatory data, reducing the risk of data manipulation, and making it possible verifying product authenticity, thereby deterring counterfeiting (Viana, 2016). In addition, blockchain enables supplier evaluation by tracing performance and reputation transparently, thereby simplifying procurement decision-making. Interoperability and data exchange among partners are supported, thereby allowing seamless collaboration to be achieved (Morse, 2018). This technology also aids sustainability by providing insights into sourcing and the ability to track ethical material sources. Figure 4 shows the major blockchain mechanisms applied in supply chain systems, and Table 1 lists the prominent implementations in various industries. These applications range from transportation, manufacturing, and agriculture to healthcare, logistics, and even vaccine distribution. Each instance highlights how blockchain addresses specific issues, such as traceability, compliance, counterfeit prevention, and data integrity. For example, in transportation, blockchain provides a secure method for verifying delivery schedules and shipment statuses, thus improving visibility and trust (Larios-Hernández, 2017). In Industry 4.0 manufacturing, the integration of blockchain with distributed storage systems, such as the InterPlanetary File System (IPFS), ensures data integrity and availability. In food and agricultural supply chains, blockchain technology integrated with IoT sensors provides real-time monitoring of produce from farm to table, facilitating food safety and authenticity (Guo and Liang, 2016). During the COVID-19 pandemic, blockchain-based platforms were established to ensure the traceability and authenticity of vaccine distribution using private and public ledgers to promote throughput and transparency (Adam et al., 2023). In some agri-food businesses, smart contracts in multi-agent systems have automated supply chain processes, ensuring accountability and reducing the need for manual intervention. Even the maritime sector has employed blockchain to improve bunker fuel delivery verification in adherence to new regulations. In addition to traceability and automation, blockchain-based smart contracts automatically release payments on delivery confirmation, minimize delays, and eliminate intermediary fees (Matenga and Mpofu, 2023). The integration of blockchain with IoT and RFID devices improves real-time tracking, allowing supply chain managers to act ahead of disruption or quality problems. Supplier management is also improved via decentralized reputation systems that record past performances, enabling objective and reliable partner evaluations (Agrawal et al., 2021). Despite these advantages, there are several

obstacles to widespread adoption. Scalability remains an acute issue, especially for systems

that process high transaction volumes. Most existing platforms cannot manage the computational and energy requirements to support supply chains on a large scale. Interoperability between different blockchain systems and existing legacy systems remains limited, and there is a general lack of standardized frameworks and protocols. Small businesses, such as construction localized to a region or farming in rural areas, have adoption barriers owing to technical and economic constraints. Furthermore, most current applications are in the domain of data recording rather than predictive analysis. Although blockchain makes data immutable, its integration with artificial intelligence for supply chain prediction and optimization remains largely unexploited. Modifications in certain domains, especially in sectors such as renewable energy and precision agriculture, must be developed and researched in a customized manner. Table 1 provides an overview of key research studies, including the issues addressed, conceptual frameworks applied, and the resulting benefits of blockchain applications across different supply chain settings. As technology continues to evolve, its potential contribution to building resilience, transparency, and sustainability in global supply chains can grow exponentially if scalability, interoperability, and compliance with regulations are adequately addressed.

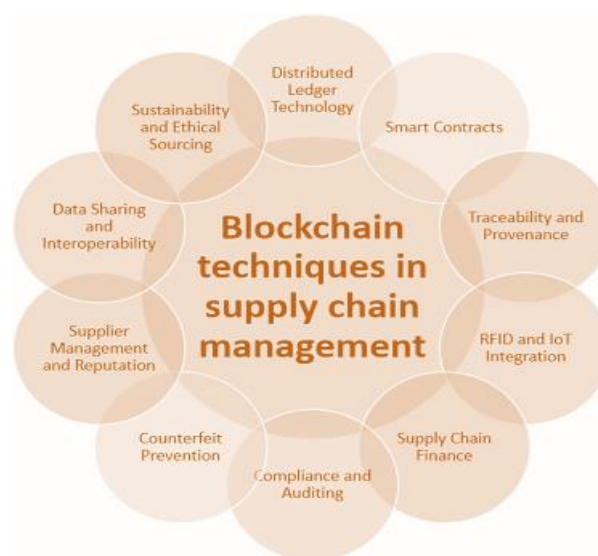


Figure 4: Blockchain Techniques in Supply Chain Management (Kumar et al., 2025).

Table 1: Blockchain techniques in supply chain management				
Industry/Service Provider	Problem Addressed	Concept	Solution	Benefits
Transportation	Tracking difficulties and lack of real-time info	Blockchain-stored delivery details	Immutable records increase data trust	Boosts transparency and supplier credibility
Industry 3.0 & 4.0 (Manufacturing)	Data capture and storage challenges	Blockchain + IPFS for distributed data storage	Distributed systems enable large-scale storage	Supports scalable and resilient operations
Food, Automotive, Aerospace, Logistics	Need for traceability	DLT-based supply chain tracking	Data-driven Supply Chain Traceability (SCT)	Improves transparency and compliance
Cobalt Industry	Lack of ESG oversight	Blockchain-linked ESG monitoring	Frameworks for compliance and transparency	Supports responsible sourcing practices
Agriculture	Factory monitoring issues	Ethereum + IoT tracking	Digital records of shareholder activities	Improves visibility and traceability
COVID-19 Vaccines	Traceability & fraud detection	Private-Public blockchain network	Vacledger + distributed file system	Ensures authenticity and real-time access

Table 1 (cont): Blockchain techniques in supply chain management

Agri-food	Lack of automation	Smart contracts in multi-agent systems	Blockchain-automated supply chain management	Reduces manual errors, improves detection
Bunker Supply	Bunker quality disputes		Electronic bunker notes for compliance	Builds trust and meets IMO 2020 regulations

3. BLOCKCHAIN APPLICATIONS ACROSS INDUSTRIES

Blockchain technology has gained widespread traction across numerous industries owing to its decentralized, transparent, and secure nature. At its core, blockchain is a distributed ledger system that allows data and transactions to be recorded across a network of computers, thereby ensuring data integrity and tamper resistance.

This innovative approach addresses the long-standing challenges of various industrial operations. However, despite its potential, blockchain still faces hurdles, such as regulatory ambiguity and scalability issues. Ongoing research and technological advancements are gradually helping mitigate these challenges. As blockchain continues to evolve, more practical and transformative use cases are expected to emerge across diverse sectors (Table 3).

Table 3: Scope of Blockchain Technology in Industries

Reference	Industry	Scope
(Pal and Yasar, 2020)	Coffee Industry	Proposed a blockchain-enabled framework to enhance supply chain processes and introduce transparency into operations.
Burgess et al., 2022)	Railcar Industry	Utilized lifecycle assessment (LCA) integrated with blockchain and configuration management to improve traceability in railcar remanufacturing.
(Ebrahim et al., 2022)	Textile and Clothing	Applied blockchain to validate traceability of organic cotton using mass balancing procedures.
(Pal, 2021)	Oil Industry	Recommended blockchain for improving efficiency and transparency in complex oil sector supply chains.
(Kohli et al., 2023)	Textile and Clothing	Developed a blockchain and IoT-integrated solution for secure transactions and supply chain traceability in the garment industry.
(Wang et al., 2019)	Fashion Industry	Explored blockchain's role in increasing transparency and combating greenwashing in fashion supply chains.
(Kamble et al., 2019)	Food Industry	Designed a blockchain-based quality control system tailored for local food delivery networks.
(Chang et al., 2020)	Pharmaceutical	Built a blockchain-driven recall management system to improve data transparency, integrity, and efficiency in pharmaceutical supply chains.
(Lotfi et al., 2024)	Supply Chain Finance	Introduced BC4Regu, a blockchain-IoT solution aimed at reducing information asymmetry and improving data reliability in financial transactions within supply chains.

In the renewable energy sector, blockchain is still emerging, with limited end-to-end implementation. Peer-to-peer (P2P) energy trading models using smart contracts remain underdeveloped because of the absence of standardized regulations and technical frameworks. Moreover, the integration of blockchain with AI and machine learning for predictive analysis and fault detection in energy systems requires further research. Several barriers hinder the wider adoption of blockchain technology. Scalability remains a critical issue, especially for public blockchains such as Bitcoin and Ethereum, which struggle to handle large transaction volumes (Garah et al., 2024). To counter this, solutions such as sidechains, sharding, and layer-two protocols are under development. Private or consortium blockchains offer more scalable alternatives to enterprise-level applications. Interoperability is another significant challenge in this regard. Many legacy systems do not integrate well with blockchain technology, making data exchange cumbersome and inefficient. Standardized APIs, cross-chain platforms, and atomic swap protocols can bridge these gaps, allowing for seamless integration and communication between diverse systems. Data privacy and security are pressing concerns. Although blockchain is secure by design, industries dealing with sensitive data require extra safeguards. This can be addressed through permissioned blockchains, advanced encryption, and privacy-preserving methods, such as zero-knowledge proofs and homomorphic encryption. However, regulatory concerns remain a major obstacle. Compliance with industry-specific laws and regulations is essential. Establishing collaborations with regulatory bodies and creating transparent frameworks can help foster trust and guide compliant blockchain

adoption in healthcare. Another concern is energy consumption, particularly in proof-of-work (PoW) models. Transitioning to energy-efficient consensus mechanisms, such as proof-of-stake (PoS), and leveraging renewable energy sources can mitigate environmental impacts. The fast-paced evolution of blockchain technology has led to a shortage of qualified professionals. Bridging this gap requires educational partnerships, training programs, and support for open-source communities to build a skilled workforce. Furthermore, skepticism and misperceptions about the benefits of blockchain hinder its adoption in certain sectors. Awareness campaigns, demonstration projects, and case studies can illustrate the tangible advantages of blockchain technology and encourage its broader use. The high cost of implementing blockchain solutions and the difficulty in measuring return on investment also act as deterrents to its adoption. Highlighting high-impact use cases and conducting cost-benefit analyses can help justify expenditures and drive investments. In the context of sixth-generation (6G) wireless communication networks, blockchain offers promising capabilities. Its decentralized structure enhances data privacy, mitigates security breaches, and eliminates single points of failure. Smart contracts can automate network management tasks, thereby reducing latency and enabling dynamic resource allocation. Blockchain also facilitates decentralized edge computing and secure peer-to-peer communication—features critical for ultra-reliable low-latency communication (URLLC) and intelligent network slicing in 6G environments.

4. CONCLUSION

Blockchain technology continues to attract massive attention from different industries, given its game-changing capability in streamlining processes, securing transparency, and producing better digital settings. While promising, it still has several issues that need to be addressed, including challenges in scalability and performance, interoperability with existing systems, data protection and privacy, regulatory uncertainty, and high implementation costs. Moreover, adoption is frequently hindered by ignorance, skepticism, and the environmental impact of certain consensus algorithms. However, progress is being made. Sectors are shifting toward more sustainable practices by embracing energy-efficient consensus algorithms and developing tools to monitor and offset the carbon footprint of blockchain networks. Adoption is driven by major breakthroughs in traceability, digital identity, smart contracts, and integration with IoT technologies. These advancements are driving greater supply chain transparency, higher levels of automation, and facilitating secure and decentralized data sharing. The future development of blockchain will likely be shaped by regulatory advancements, better standards for interoperability, and domain-specific solutions. Future research efforts should prioritize more efficient consensus algorithms, better privacy-preserving techniques, and more accessible platforms to enable broader adoption. By addressing current challenges and plugging current research gaps, blockchain technology can potentially unlock new dimensions of transparency, efficiency and sustainability. Finally, blockchain is poised to play a central role in powering innovation and facilitating a more accountable and digitally empowered world economy.

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