

Blockchain in Supply Chain Management: A Critical Review of Benefits, Challenges, and Future Prospects

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ABSTRACT

This review paper aims to comprehensively understand how Blockchain technology has emerged as a driving force in supply chain management, bringing in transformative changes and offering unparalleled transparency, security, and efficiency across various domains. By creating an immutable and decentralised ledger, blockchain revolutionises how goods and information flow in a supply chain network from manufacturers to consumers. The study explores the challenges modern supply chains face and the benefits of blockchain integration, including enhanced traceability, reduced fraud, and streamlined processes in the supply chain. It delves into use cases of prominent companies successfully implementing blockchain to optimise their supply chains. The difficulties and limitations associated with blockchain adoption, such as interoperability issues, regulatory concerns, and cultural resistance in the current supply chain networks, have also been discussed. In a rapidly changing global economy, understanding the transformative capacity of blockchain in supply chain management holds utmost significance. This study contributes to the comprehension of the various applications of blockchain technology in the current supply chains. It gives organizations reasons to reconsider the promising aspects of blockchain integration in their supply chains to adapt to changing consumer demands and maintain the lead in an increasingly competitive and dynamic marketplace.

Keywords: Blockchain, Supply Chain, distributed ledger, smart contracts, information sharing

1.0 INTRODUCTION

The complexity of supply chains has increased over the years since the onset of globalisation. Advancements on the technology front have enabled businesses to operate internationally, collaborating with partners and suppliers from across the globe. On one side, this has reduced expenses and raised efficiency, but on the other, it has brought new difficulties. A supply chain network comprises different elements such as suppliers, distributors, end users, and other participants. The network is linked together through physical flows, which involve the production, transportation, movement, and storage of goods and materials, as well as information flows, which allow the various supply chain members to control the daily flow of goods and materials up and down the supply chain and coordinate their long-term plans and (Zhou & Piramuthu, 2015). Integrating logistics, money flow, and information flow efficiently to cut costs and boost efficiency is the primary goal of supply chain management. Supply chains are highly complicated due to increased globalisation, varying customer demands, extended

product lines, uncertainty about supplier performance, and many other associated concerns (Ateş et al., 2021). Security and transparency are top priorities for enterprises. In traditional supply chains, maintaining visibility over the entire network is one of the most significant issues supply chain managers face today. Effective supply chain control requires end-to-end process visibility, from procurement to customer delivery (Azhar, 2023). Tracking and tracing goods and products accurately can be challenging at the same time as goods move from one location to another. The absence of transparency can result in delays, errors, fraud and counterfeiting issues. Supply chains also face issues with information sharing and trust. Information technology (IT) has emerged as an essential component of supply chain management systems for information collaboration and performance enhancement by adding technology components to traditional supply chains' daily management work for gathering, processing, analysing, storing, and sharing large amounts of information in a real-time manner (Smith et al., 2007). One such technology is blockchain, a new distributed information technology which can play a significant role in building a decentralised, open, transparent, and safe network that enables the real-time tracking of products at every step of the organisation's supply chain. It provides an immutable ledger, guaranteeing data integrity while granting real-time access to information for all participants on the network.

2.0 LITERATURE REVIEW

2.1 BACKGROUND

A supply chain is an intricate network comprising organisations, individuals, activities, information, and resources collaboratively engaged in the seamless movement of a product or service from supplier to customer. Its purpose is to maintain the quality and integrity of goods and products throughout shipment (Azzi et al., 2019).

Among the significant challenges confronting contemporary supply chain managers is maintaining visibility across the entire network. Centralised supply chain management systems increasingly expose the supply chain to corruption, fraud, and tampering (Azzi et al., 2019). As goods travel from one place to another, the capacity to monitor their progress with pinpoint accuracy is a task far from trivial. The absence of this transparency can give rise to various issues, including untimely disruptions, inaccuracies, and instances of fraudulent activity. Identifying solutions to such problems has now become a priority for businesses. The challenges remain as pertinent as ever, underscoring the need for innovative solutions in a perpetually evolving industry (Günthner, 2023). Furthermore, it is crucial to guarantee each entity's and process's confidentiality, security, legitimacy, dependability, and integrity (Tiwari, 2020). A more significant lack of confidence is caused by ineffective transactions, fraud, theft, and underperforming supply chains; as a result, there is a need for improved information exchange and verifiability (Saberli et al., 2018). For regulatory agencies and final consumers, a product's capacity to track its origins is becoming increasingly crucial. Traceability can give manufacturers of high-value goods—like pharmaceuticals, agricultural inputs, and anything else that has value to counterfeiters—a competitive advantage. The capacity to definitively determine the product's manufacturing time, origin, and vendor represents a valuable proposition for both the consumer and the manufacturer. It is a robust assurance of product quality and safeguarding intellectual property rights. Paper-based receipts and certificates are susceptible to unauthorised duplication or alterations by counterfeit actors, whereas digital records protected by cryptographic techniques offer robust security and immutability. These

digital records are pivotal in instilling trust among intermediaries and principal stakeholders engaged in a complex supply chain. For instance, trust breakdowns and severe financial repercussions experienced by companies during outbreaks, like the Salmonella contamination associated with papayas or the E. Coli incidents connected to Chipotle Mexican Grill, could have been mitigated if consumers had the means to trace the source of these products securely. This way, the specific food item responsible for the outbreak could have been promptly isolated and identified (Alqarni et al., 2023). Not only did these incidents affect people’s health, but businesses also underwent damage. Many recent Food and Drug product recall cases have been published on the FDA websites (Affairs, 2023).

According to a Forbes report published on April 25, 2024, the most notable food recalls so far in the US in 2024 have been as indicated in Table 1 below (Johnson, 2024):

Table 1: Food Product Recall Cases

Food Recall Case	Company Involved
Trader Joe's 61,000 pounds of steamed chicken soup dumplings were recalled in March by CJ Foods Manufacturing Beaumont Corporation due to potential hard plastic contamination from a permanent marker.	Trader Joe
The FDA issued a warning in March about unsafe lead levels on six grounds of cinnamon products following a 2023 recall involving over 500 adverse child events.	Products were sold in discount stores like Dollar Tree and Family Dollar across several states in the US.
Quaker Oats recalled over 20 products in January due to salmonella contamination, including granola, protein, cereal bars, cereals, instant oatmeal, and snack mixes, with no adverse events reported.	Quaker Oats
The FDA has reopened an investigation into a listeria outbreak linked to dairy products from Rizo-Lopez Foods, leading to a recall of around 60 items. Retailers like Walmart, Costco, and Trader Joe's also recalled related products. The outbreak, which began in 2014, resulted in 26 cases, 23 hospitalizations, and two deaths.	Rizo-Lopez Foods

A company facing a product recall experiences a significant loss of reputation stemming from adverse publicity, resulting in a dramatic reduction in sales. Throughout the investigation, all products associated with the recall were adversely affected, with some businesses suspending operations until the root cause of the supply chain breach was identified (Kshetri, 2018). Numerous technology providers present a spectrum of traceability system platforms, encompassing Artificial Intelligence, barcodes, Big Data, Cloud computing, Machine Learning, Internet of Things (IoT), Radio Frequency Identification (RFID), Quick Response (QR) codes, wireless sensor networks (WSNs), and blockchain (Astuti & Hidayati, 2023).

Global Counterfeiting: Economic, Safety, and Supply Chain Challenges

Counterfeit networks permeate every corner of the globe, with significant hubs in China, Hong Kong, Bangladesh, Turkey, India, and Vietnam. Modern counterfeits are sold through various channels, from social media platforms like TikTok, Facebook, and Instagram to online marketplaces like Amazon, AliExpress, and Alibaba. Studies suggest that nearly half of the products procured from these platforms are counterfeit. The US Chamber of Commerce estimates a \$500 billion annual economic loss due to counterfeit goods, affecting 2.5 million legitimate jobs and posing a threat to consumer safety across industries. Unregulated replicas often contain dangerous substances, posing health risks and property damage. In 2018, British law enforcement intercepted counterfeit cosmetics, posing as reputable brands like MAC, Dior, and Chanel. These imitations contained toxic agents, including mercury, capable of causing severe harm to the nervous system, lungs, skin, and eyes (Asia, 2023). In addition to counterfeiting and other physical threats that remain a crucial concern for supply chain managers, managers of modern supply chains encounter a growing number of information security-related challenges. The growth of the Internet infrastructure is responsible for the rise in these issues, as effective supply chains now depend on shipments, inventories, and equipment conditions, among other things. Due to our increasing reliance on technology, malicious individuals have new avenues to disrupt supply chains, steal sensitive information, and even squander money (Hassija et al., 2021; Wainstein, 2020). The blockchain trail can trace a counterfeit to its source (Gaur, 2020).

2.2 BLOCKCHAIN TECHNOLOGY

Blockchain, one of the most prominent innovations of our time, has gained widespread adoption across various sectors and witnessed a substantial surge in significance. Blockchain provides a ledger of distributed data (What Is Blockchain?, n.d.), updated and maintained by a computer network that validates a transaction before approving and adding it to the ledger (Morkunas et al., 2019). Nakamoto (2008) initially developed blockchain as a platform for unrestricted electronic transactions. This framework utilises a peer-to-peer network employing proof-of-work to uphold an open ledger of transactions. It presumes that authentic nodes command most computational resources, making malicious manipulations highly challenging. Blockchain serves as an illustration of leveraging distributed systems to facilitate access to publicly accessible information. This technology ensures security through key attributes like decentralisation, immutability, robustness, and smart contracts, reducing reliance on intermediaries. A Certificate Authority identifies network members, ensuring all nodes are authenticated, and their identities are known to all other nodes. (Dinh et al., 2017). Considerable research efforts have been put into exploring the capabilities and implications of blockchain technology. It has since experienced a radical development, emerging as a disruptive innovation with the potential to revolutionise how we engage in electronic communications, handle financial transactions and oversee their tracking and monitoring. The blocks that make up the blockchain are connected chronologically to form a chain. Each block comprises a collection of transactions that have been validated by nodes, which are network members. A block cannot be removed or changed once added to the chain. The technology's decentralised feature makes it superior to traditional databases, usually managed by a single entity. Blockchain enables multiple parties to join the network and verify transactions. This indicates that neither a single point of failure nor a central point of control exists (Azzi et al., 2019).

There are various types of blockchain networks, depending on who manages them as follows:-

- A Public Blockchain refers to an open and permissionless network where participation is unrestricted, allowing anyone to engage. Commonly associated with various cryptocurrencies, a public blockchain operates under defined rules or consensus algorithms. Different cryptographic techniques enable users to enter the network and log their transactions while preserving trust with many anonymous users (Pilkington, 2015).
- A Closed or Private Blockchain allows organisations to control who can access blockchain data. Only users granted permission can access specific data sets (What Is Blockchain? n.d.). This type of blockchain eliminates anonymity by allowing parties to know one another, much like in a supply chain network where well-known entities collaborate to produce and distribute goods. New positions would emerge in this scenario, such as certifiers who uphold this private network and grant certifications to supply chain network users (Sabeti et al., 2018).
- A Federated or Consortium blockchain network is one where a preselected set of nodes or stakeholders closely controls the consensus process (mining process) (What Is Blockchain? n.d.).

Since blockchain may be used to solve database and communications issues, these features present exceptional opportunities for information sharing and real-time synchronisation in supply chain management (Kshetri, 2018).

2.3 HOW BLOCKCHAIN IMPROVES SUPPLY CHAIN EFFICIENCY?

Supply chain networks are overly complicated due to the participation of several individuals, organisations, lawmakers, and potentially even nations. Supply chains face challenges such as trust generation, cyberattacks, cargo theft, and counterfeiting, which are the most prominent (Hassija et al., 2021). To realise a connected world with no boundary restrictions regarding goods and services, it is imperative to keep supply chains transparent, secure, and trustworthy. Blockchain promises security as data can only be changed with consensus from the network participants once recorded on the blockchain. This has been made possible due to the use of diverse cryptographic techniques. The blockchain network is constantly monitored by the network nodes, each with a copy of the blockchain. Within a blockchain system, fraud and data tampering are thwarted as data cannot be modified without the consensus of a quorum of involved parties. The blockchain ledger is shareable yet immutable, meaning any attempt to alter data triggers alerts to all participants, revealing the perpetrator's identity (What Is Blockchain? n.d.). It is practically impossible for malicious attackers to compromise the security of a blockchain network by inserting fraudulent blocks into the ledger.

Blockchain promises enhanced cost-effectiveness, negating the need for centralised authorities to govern and regulate interactions and transactions among multiple participants. It establishes secure information platforms to tackle economic, business, societal, and political challenges. Furthermore, this platform has garnered widespread adoption across various sectors, including trade (Yoon et al., 2020), banking (Hassani et al., 2018), healthcare (Attaran, 2022), and logistics and transportation (Koh et al., 2020). Its decentralisation and security make it an ideal supply chain management solution where transparency and trust between parties are crucial (Günthner, 2023). Blockchain can significantly enhance supply chains by facilitating more

rapid and cost-efficient product delivery, boosting product traceability, enhancing partner coordination, and facilitating financing access (Gaur, 2020). The main features of blockchain technology that set it apart from most current information systems designs are non-localisation (decentralisation), security, auditability, and intelligent execution (Saber et al., 2018) (see Figure 1).

Figure 1: Blockchain Architecture (Saber et al., 2018)



Smart contracts are another essential element of the blockchain. They are executable codes stored on the blockchain and activated automatically upon fulfilling predetermined conditions. These contracts enforce an agreement between untrusted parties without the involvement of a trusted third party. Smart contracts enabled network automation and the conversion of paper contracts into digital ones (Khan et al., 2021). Crucially, once deployed, they become immutable and reside on a decentralised ledger integrated within a blockchain network.

Within the logistics supply-chain system context, a smart contract can be collaboratively formulated through negotiations among the system's partners and stakeholders. Subsequently, this smart contract can be deployed onto the blockchain to ensure adherence to the predetermined service terms and product quality standards, facilitating the seamless operation of the supply chain. A vital attribute of a smart contract is its capacity to automatically update the ledger in response to the execution of its code, provided that all participating actors have successfully fulfilled the contract's stipulated terms (Alqarni et al., 2023). Smart contracts enable monitoring operational parameters and sending notifications to prevent damage during transportation (Chen et al., 2020). Additionally, as Saber et al. (2018) noted, smart contracts facilitate ongoing process improvement between parties. This includes setting conditions that initiate purchase orders for replenishment (Pournader et al., 2019) and determining loan payments when funds are available (Schuetz & Venkatesh, 2020). Figure 2 depicts the benefits of a smart contract system deployed on a blockchain network.

Figure 2: Benefits of Smart Contracts (Alqarni et al., 2023)



Despite notable advancements in recent years, smart contracts still face numerous challenges. A noticeable example is the infamous malicious attack in 2016, wherein the Decentralized Autonomous Organization (DAO) smart contract was manipulated to steal approximately 2 million Ether (equivalent to 50 million USD). This breach occurred due to the exploitable reentrancy vulnerability within the smart contract system (Finley, 2016). Besides the vulnerability issue, smart contracts must also deal with privacy, legal, and performance concerns (Khan et al., 2021).

Tracking and tracing are pivotal in upholding product quality across the food supply chain. The conventional framework for traceability systems is time-consuming and more vulnerable to hacking, privacy breaches, data manipulation, and fraud (Westerlund et al., 2021). Blockchain's primary characteristic is its transparent and immutable ledger of all supply chain transactions. This feature simplifies tracking products from origin to destination, enhancing accountability and minimising the potential for fraudulent activities. Furthermore, it fosters heightened transparency throughout the supply chain, enabling companies to monitor real-time product movements and performance. Consequently, this real-time visibility can enhance trust among supply chain partners. Blockchain is a promising distributed ledger technology with many possible uses, especially in supply chain management (Sunny et al., 2020). In a blockchain network, transactions are always time-stamped and up to date. This capability empowers companies to inquire about a product's real-time status and location at any given moment. Such functionality proves instrumental in addressing challenges such as counterfeit goods, compliance breaches, delays, and wastage. Blockchain is emphasised to overcome one-step-forward and one-step-back methods in supply chain operations by achieving traceability and end-to-end transparency based on accurate and timely information availability (Cole et al., 2019). Moreover, it facilitates swift responses during emergencies, such as product recalls, and the ledger audit trail ensures regulatory compliance. Moreover, by combining blockchain with innovative technology like the Internet of Things, supply chains can automate the tracking of production conditions, transportation, and quality control. Companies can also share track and trace data with customers to verify product authenticity and ethical supply chain practices (*Blockchain for Supply Chain: Track and Trace*, n.d.)

The literature review shows that Blockchain technology has immense potential to transform the supply chain landscape by enhancing traceability, providing transparency and robust security, increasing speed and reliability, and improving contracting and financial transactions.

3.0 NOTABLE PLAYERS IN BLOCKCHAIN

Amazon utilises blockchain technology through its Amazon Managed Blockchain service, allowing supply chains to document updates in a shared ledger. This service is managed by Amazon Web Services, which simplifies the creation and deployment of scalable blockchain networks on Hyperledger Fabric and Ethereum. This innovation demonstrates Amazon's commitment to innovation and provides cutting-edge solutions. Amazon Managed Blockchain streamlines the creation and management of scalable blockchain networks, providing secure access to public blockchains like Ethereum and Bitcoin. Ava Labs, a company supporting video game-specific blockchain, is partnering with Amazon for blockchain adoption. Major companies like AT&T Business, DTCC, Sony Music, Guardian Life Insurance, UBX, Chainstack, Verizon, Nestle, and TrackX utilise Amazon's blockchain platform (Rathod, 2024).

A US retail giant, **Walmart**, has implemented blockchain technology in its decentralised food supply ecosystem. The company developed a food traceability system using Hyperledger Fabric, tested in two proof-of-concept initiatives. The system enabled authenticity certifications for pork in China, increasing system confidence, and reduced the time required to determine the origin of mangoes in the US from 7 days to 2.2 seconds (How Walmart Brought Unprecedented Transparency to the Food Supply Chain with Hyperledger Fabric, 2023).

DHL, a German logistics company, has partnered with Accenture to use blockchain technology to improve logistics efficiency, traceability, and transparency. The company's blockchain-based serialisation prototype aims to minimise tampering and counterfeiting medications in the life sciences and healthcare sector by tracking and authenticating pharmaceuticals along the supply chain. The prototype can conduct up to 1,500 transactions per second and accommodate seven billion unique serial numbers. DHL Express is also developing a blockchain-based invoicing system, which streamlines quotation approval, increases transparency, and generates invoices automatically, leading to faster and more cost-effective operations (DHL,2024).

4.0 CHALLENGES AND FUTURE PROSPECTS

Blockchain technology has significantly influenced various aspects of our lives and society by enabling new ways of value creation and exchange that were once impossible or impractical. It has facilitated innovative methods of collaboration and cooperation across different domains and sectors, opening up unprecedented opportunities for integration and partnership. The adoption of blockchain technology faces challenges such as interoperability, energy consumption, scalability issues, regulatory uncertainty, security, public perceptions, ethical considerations, and lack of awareness and skills, necessitating the resolution of these issues for successful implementation in business. According to a Statista report published in May 2024, blockchain technology is forecast to increase to nearly 1,000 trillion US dollars by 2032. AI-integrated blockchain technology is expected to enhance efficiency in 2024, enhancing decision-making and genetic algorithms. Decentralised Finance (DeFi) is expanding and introducing new facets like SocialFi, GameFi, and InsureTech. Ethereum's smart contract capabilities fuel this growth, addressing SMEs and emerging markets and enhancing transparency, efficiency, and innovation.

5.0 CONCLUSION

In conclusion, the rapidly evolving landscape of blockchain technology presents both disruptive potential and significant challenges. Addressing the challenges the blockchain industry faces today is essential for harnessing blockchain's full potential and guiding it toward a sustainable and innovative future. Organisations leveraging this technology stand to gain a significant competitive edge in a landscape where the importance of data is steadily increasing. There is a growing need for industry-wide collaboration, standardised frameworks, and significant research advances to maximise blockchain's potential.

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