



Blockchain Technology in Supply Chain Management: A Review of Business Applications and Future Directions

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Abstract

Blockchain technology has the potential to revolutionize supply chain management (SCM) by increasing transparency, improving efficiency, and reducing costs. This paper reviews the business applications of blockchain technology in SCM and identifies future directions for its use. We explore the current applications of blockchain technology in SCM, including tracking and tracing of goods, verification of product authenticity, and automating supply chain processes. Then, we examine the benefits and challenges of implementing blockchain technology in SCM and discuss the potential impact on various stakeholders, including suppliers, manufacturers, distributors, retailers, and consumers. Following, we identify future directions for research and development in blockchain technology for SCM, including the integration of AI and ML, the use of smart contracts, and the development of new blockchain-based business models.

Keywords: Blockchain; Supply Chain Management; Business Intelligence

1. Introduction

Supply chain management (SCM) is a critical business function that involves the coordination and management of all activities involved in the production and delivery of goods and services. It encompasses the planning, sourcing, manufacturing, and distribution of products, as well as the management of relationships with suppliers, distributors, and customers. Effective SCM can provide numerous benefits to businesses, such as increased efficiency, reduced costs, and improved customer satisfaction. However, managing a supply chain can be complex and challenging, particularly in today's global economy where supply chains can be extensive and involve multiple partners across different geographic regions. As a result, businesses need to adopt effective SCM strategies and leverage technology to optimize their supply chain operations and remain competitive in today's market.

Blockchain technology has emerged as a promising solution to many of the challenges facing SCM today. By providing a decentralized, transparent, and immutable ledger, blockchain technology can help to increase the visibility and traceability of goods as they move through the supply chain. This can improve the accuracy and efficiency of tracking and tracing processes, enable real-time monitoring of inventory levels, and enhance the authenticity and integrity of product information. Additionally, blockchain technology can help to streamline supply chain processes by automating contract execution, reducing the need for intermediaries, and improving payment processing. While there are still challenges to be addressed, such as scalability and interoperability, blockchain technology is already being used in various SCM applications, and its potential for transforming the supply chain industry is significant.

The motivation to review the business applications of blockchain in SCM stems from the increasing recognition of the critical role that SCM plays in business operations and the potential benefits that blockchain technology can offer

in optimizing supply chain processes. SCM is a complex and often fragmented process, involving multiple parties and a vast amount of data that can be prone to errors, delays, and fraud. Blockchain technology, with its decentralized and immutable ledger, has the potential to revolutionize SCM by providing a transparent, secure, and efficient platform for tracking and tracing products, managing contracts and payments, and sharing data among supply chain partners. As such, there is a growing interest in exploring the applications of blockchain in SCM and identifying the best practices for its implementation.

Our paper makes several important contributions to the field of SCM and blockchain technology. These include:

- Providing a comprehensive review of the current business applications of blockchain in SCM, which includes tracking and tracing of goods, verification of product authenticity, and automating supply chain processes.
- Identifying the benefits and challenges of implementing blockchain technology in SCM, including increased transparency, improved efficiency, reduced costs, and the need for careful consideration of specific business needs and circumstances.
- Discussing the potential impact of blockchain technology on various stakeholders in the supply chain, such as suppliers, manufacturers, distributors, retailers, and consumers.
- Identifying future directions for research and development in blockchain technology for SCM, including the integration of artificial intelligence and machine learning, the use of smart contracts, and the development of new blockchain-based business models.
- Highlighting the potential of blockchain technology to transform SCM and providing recommendations for businesses to explore the use of this technology to gain a competitive advantage in their respective industries.

This paper is organized in five sections. After introducing the topic in section 1, we provide the background information about the topic in section 2. Section 3 discusses different business applications. The future research directions of this topic is covered in section 4. Section 5 has the conclusion of the paper.

2. Background

Blockchain technology is a decentralized, distributed ledger technology that enables secure and transparent transactions without the need for a trusted intermediary. It was first introduced as the underlying technology behind the digital currency, Bitcoin, in 2008 by an anonymous person or group using the pseudonym "Satoshi Nakamoto." Since then, blockchain technology has evolved to include a range of applications beyond digital currencies, including SCM, identity management, and smart contracts. A blockchain is essentially a database that contains a continuously growing list of records, called blocks, which are linked and secured using cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data. Once a block is added to the blockchain, it cannot be altered or deleted, providing a secure and tamper-resistant record of all transactions.

There are several types of blockchains, including public, private, and hybrid blockchains. Public blockchains are open to anyone and are often used for digital currencies and other decentralized applications. Private blockchains are controlled by a single entity or organization and are used for applications that require privacy and permission access. Hybrid blockchains combine the features of both public and private blockchains, offering the benefits of both.

Table 1: Summary comparisons between different types of blockchain for SCM.

Criteria	Public Blockchain	Private Blockchain	Hybrid Blockchain	Consortium Blockchain	Federated Blockchain
Access	Open and permissionless	Controlled and permissions	Controlled and permissions	Controlled and permissions	Controlled and permissions
Participants	Anyone can join	Limited to specific participants	Can be open or limited	Limited to pre-approved organizations	Limited to a group of organizations with a shared interest
Governance	Decentralized	Centralized	Decentralized or centralized	Shared governance among consortium members	Shared governance among

Consensus Mechanism	Proof of Work, Proof of Stake	Various (e.g., Practical Byzantine Fault Tolerance, Raft)	Various (e.g., Proof of Authority, Delegated Proof of Stake)	Various (e.g., Byzantine Fault Tolerance)	Various (e.g., Raft, Practical Byzantine Fault Tolerance)
Security	High, but vulnerable to 51% attacks	High, as access is limited	Depends on the implementation	High, as access is limited and governed by pre-approved organizations	High, as access is limited and governed by participating organizations
Scalability	Limited due to large network size and PoW consensus	This can be higher due to smaller network size and more efficient consensus	Depends on the implementation	Can be higher than public blockchain, but lower than private blockchain	Can be higher than private blockchain, but lower than public blockchain
Transparency	Fully transparent	Limited to participants	Can be fully or partially transparent	Partially transparent to members only	Partially transparent to members only

There are also several consensus mechanisms used in blockchain technology, including Proof of Work (PoW), Proof of Stake (PoS), and Byzantine Fault Tolerance (BFT). PoW is used in Bitcoin and other cryptocurrencies and involves solving complex mathematical problems to validate transactions and add new blocks to the blockchain. PoS, on the other hand, involves validators staking their cryptocurrency holdings to validate transactions and add new blocks to the blockchain. BFT is used in private and consortium blockchains and involves a group of validators reaching a consensus on transactions through a voting process. Table 2 provides a comparative review of the literature consensus mechanisms.

Table 2: Summary comparisons between different consensus mechanisms.

Criteria	Proof of Work	Proof of Stake	Delegated Proof of Stake	Proof of Authority	Practical Byzantine Fault Tolerance
Energy Efficiency	Low	High	High	High	High
Scalability	Limited	High	High	High	High
Security	High	High	High	High	High
Decentralization	High	Low	Low	Low	High
Block Production	Slow	Fast	Fast	Fast	Fast
Economic Incentives	Mining rewards	Staking rewards	Block producer rewards	Block validator rewards	Block validator rewards
Susceptibility to centralization	High	High (depending on coin distribution)	High (limited number of validators)	High (depending on authority)	Low
Resistance to 51% attack	High	High	Low (depending on the number of validators)	High	High
Validator Selection	Random	Deterministic based on the stake	Elected by coin holders	Chosen by a centralized authority	Elected by participating nodes

Business Use Cases	SCM, trade finance, digital identity	Asset management, decentralized exchanges	Enterprise blockchain solutions	Private and permissioned blockchains, public blockchains	Private and permissioned blockchains
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3. Overview of Business Applications

3.1. Traceability and provenance tracking

Blockchain technology has shown significant potential in revolutionizing traceability and provenance tracking in SCM. By leveraging the decentralized and immutable nature of blockchain, businesses can create a transparent and trustworthy system for tracking the origin, movement, and history of products throughout the supply chain. Each transaction or movement of goods can be recorded as a block on the blockchain, creating an unalterable and auditable chain of custody. This enables stakeholders to have a complete and accurate view of the product's journey, ensuring transparency and accountability.

The application of blockchain for traceability and provenance tracking brings numerous benefits to SCM. Firstly, it enhances product authenticity by allowing stakeholders to verify the authenticity and origin of products. This is particularly valuable in industries such as food and luxury goods, where counterfeiting and fraud are prevalent concerns. Secondly, it enables efficient and rapid identification and resolution of supply chain issues such as recalls, quality control, or compliance violations. By quickly tracing the source of a problem, businesses can minimize the impact and protect consumer safety. Lastly, blockchain-based traceability enhances consumer trust and confidence in brands. Customers can access information about the product's journey, including sourcing, manufacturing, and handling practices, fostering transparency and supporting ethical consumer choices. Table 3 provides an overview of the literature on blockchain for improving traceability and provenance in SCM.

Table 3: Summary of blockchain applications for traceability and provenance tracking.

Benefit	Description	Key Stakeholders	Key Use Cases	Challenges	Examples	References
Enhanced product authenticity	Blockchain allows stakeholders to verify the authenticity and origin of products, minimizing the risk of fraud and counterfeiting.	Manufacturers, suppliers, retailers, regulators, and consumers	Luxury goods, pharmaceuticals, food and beverages, and high-value items	Ensuring data accuracy and integrity, interoperability, and standardization	LVMH, De Beers, Pfizer, Walmart	[11], [2], [3], [5]
Rapid issue identification and resolution	Blockchain-based traceability enables quick identification and resolution of supply chain issues, such as recalls, quality control, or compliance violations.	Manufacturers, suppliers, regulators, and consumers	Food safety, product recalls, regulatory compliance, and quality control	Ensuring data accuracy and integrity, interoperability, and standardization	Nestle, IBM Food Trust, FSMA, Maersk	[9], [1], [0], [18]
Improved transparency and accountability	Blockchain provides a transparent and auditable chain of custody, promoting accountability	Manufacturers, suppliers, retailers, regulators,	Conflict minerals, human rights violations,	Ensuring data accuracy and integrity, interoperabil	De Beers, IBM, Everledge r,	[10], [9], [2], [13]

	and ethical business practices.	and consumers	and ethical sourcing	ity, and standardization	Provenance	
Enhanced consumer trust and confidence	By providing customers with information about the product's journey, blockchain-based traceability enhances consumer trust and supports ethical consumer choices.	Manufacturers, suppliers, retailers, regulators, and consumers	Product labeling, ethical sourcing, and environmental sustainability	Ensuring data accuracy and integrity, interoperability, and standardization	Carrefour, UNICEF, Patagonia, Timberland	[5], [6], [10], [14]
Reduced supply chain disruptions	By providing a complete and accurate view of the product's journey, blockchain-based traceability can help identify and mitigate supply chain disruptions.	Manufacturers, suppliers, regulators, and consumers	Supply chain disruptions, inventory management, and logistics	Ensuring data accuracy and integrity, interoperability, and standardization	IBM, VeChain, Chronicle, Ambrosus	[17], [8], [10], [2]
Improved regulatory compliance	Blockchain-based traceability can facilitate regulatory compliance by providing an auditable record of product movements and handling practices.	Manufacturers, suppliers, regulators, and consumers	Regulatory compliance, product safety, and quality control	Ensuring data accuracy and integrity, interoperability, and standardization	Walmart, IBM, FDA, BSI Group	[11], [5], [3], [6]
Increased efficiency and cost savings	By automating and streamlining traceability processes, blockchain-based solutions can improve efficiency and reduce costs in the supply chain.	Manufacturers, suppliers, regulators, and consumers	Inventory management, logistics, and supply chain optimization	Ensuring data accuracy and integrity, interoperability, and standardization	IBM, Provenance, SAP, Everledger	[11], [6], [10], [8]

3.2. Inventory and asset management

Blockchain technology can also be used for inventory and asset management in SCM. The decentralized nature of the blockchain can help create a more transparent and secure inventory management system. With blockchain, supply chain participants can track the movement of goods and their status in real time, from production to delivery. Smart contracts can also be used to automate inventory management tasks, such as ordering and restocking. This can help reduce errors, lower costs, and improve overall efficiency in the supply chain. Furthermore, blockchain can also be used for asset management in SCM. Assets, such as equipment and vehicles, can be tracked using blockchain technology, which can help prevent loss, theft, or damage. Blockchain can also be used to track the maintenance and repair history of assets, ensuring that they are properly serviced and in good condition. This can help extend the lifespan of assets and reduce overall costs for the supply chain. Overall, the application of blockchain for inventory and asset management in SCM can help create a more efficient and secure supply chain. Table 4 provides an overview of the literature on blockchain for improving Inventory and asset management in SCM.

Table 4: Summary of blockchain applications for inventory and asset management.

Benefit	Description	Key Stakeholders	Key Use Cases	Challenges	Examples	References
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Real-time inventory tracking	Blockchain enables real-time tracking of inventory, allowing supply chain participants to monitor the movement and status of goods.	Manufacturers, suppliers, retailers, logistics providers	Retail, e-commerce, manufacturing	Data accuracy, interoperability, scalability	Walmart, Amazon, IBM Food Trust	[2], [1], [5]
Automated inventory management	Smart contracts on the blockchain can automate inventory management tasks such as ordering, restocking, and demand forecasting.	Manufacturers, suppliers, retailers, logistics providers	Inventory optimization, order fulfillment	Data accuracy, integration with existing systems	Procter & Gamble, Alibaba, Maersk	[14], [2], [6]
Asset tracking and authentication	Blockchain can be used to track and authenticate assets, such as equipment and vehicles, ensuring their proper use and preventing loss or theft.	Manufacturers, logistics providers, asset managers	Equipment rental, fleet management	Data accuracy, interoperability, scalability	Caterpillar, DHL, BHP	[8], [10], [11]
Maintenance and repair history	Blockchain can record the maintenance and repair history of assets, ensuring proper servicing and reducing downtime.	Manufacturers, logistics providers, maintenance providers	Equipment maintenance, warranty management	Data accuracy, integration with existing systems	Rolls-Royce, Singapore Airlines, United Rentals	[3], [22], [14]
Asset lifecycle management	Blockchain provides a transparent and auditable record of an asset's lifecycle, including acquisition, maintenance, and retirement.	Manufacturers, logistics providers, asset managers	Asset lifecycle optimization, compliance	Data privacy, scalability, industry standards	Airbus, General Electric, United Parcel Service (UPS)	[25], [11], [9]
Cost reduction and efficiency	By automating inventory and asset management processes, blockchain can reduce errors, streamline operations, and lower costs in the supply chain.	Manufacturers, suppliers, retailers, logistics providers	Supply chain optimization, cost savings	Integration with existing systems, change management	IBM, Procter & Gamble, Walmart	[5], [12], [10]

3.3. Smart contracts and automation

Smart contracts and automation are other areas where blockchain technology can be applied in SCM. Smart contracts are self-executing contracts with the terms of the agreement between buyer and seller being directly written into code. Smart contracts can automate processes, reduce errors, and eliminate the need for intermediaries in many transactions. With the help of blockchain, smart contracts can ensure that all parties adhere to the terms of the contract, and the results of the contract are recorded in a tamper-evident and immutable way. This can result in more efficient and secure SCM processes. For example, in the food industry, smart contracts can be used to automate payments to suppliers based on the quality of the delivered products. If a supplier delivers sub-standard quality products, the smart contract can automatically trigger a reduction in payment or other penalties. Smart contracts can also be used to track the condition of products during transportation and to automatically trigger actions in case of temperature or humidity deviations. This can help to ensure that products are delivered in optimal conditions and reduce the risk of spoilage or damage.

In addition to smart contracts, blockchain technology can be used to automate various SCM processes, such as procurement, logistics, and payments. For example, blockchain can be used to automate the process of verifying the authenticity of goods, which is crucial for industries such as luxury goods and pharmaceuticals. With blockchain, it becomes possible to create an immutable record of a product's journey through the supply chain, which can be used to verify its authenticity and provenance. Similarly, blockchain can be used to automate the process of tracking inventory and assets, reducing the need for manual intervention and improving accuracy. Table 5 provides an overview of the literature on blockchain for improving Inventory and asset management in SCM.

Table 5: Summary of blockchain applications for traceability and provenance tracking.

Application	Description	Benefits	Challenges
Smart Contracts for Payment and Settlement	Smart contracts automate the process of payment and settlement in a supply chain. Payment can be triggered when a certain set of predefined conditions are met, which reduces the risk of fraud and improves efficiency.	- Reduces the risk of fraud and errors in payments - Improves speed and accuracy of transactions - Provides transparency and visibility into the payment process	- Requires standardization of payment terms and conditions - May require significant investment in technology and infrastructure
Automated Supply Chain Management	Blockchain can automate certain supply chain processes such as inventory management, order processing, and logistics. This improves the efficiency of the supply chain, reduces errors, and provides real-time visibility into the status of the supply chain.	- Improves supply chain efficiency and reduces errors - Provides real-time visibility into the supply chain - Reduces costs associated with supply chain management	- Requires integration with existing supply chain systems and processes - May require significant investment in technology and infrastructure
Digital Identity Management	Blockchain can be used to create a digital identity for each participant in the supply chain, which can be verified and authenticated by other participants. This improves trust and reduces the risk of fraud.	- Improves trust between supply chain participants - Reduces the risk of fraud and errors in supply chain transactions	- Requires agreement on identity verification standards and protocols - May require significant investment in technology and infrastructure

3.4. Payment and settlement

One of the most prominent use cases of blockchain in SCM is payment and settlement. Blockchain technology provides a secure and transparent payment infrastructure that eliminates the need for intermediaries and reduces transaction costs. Blockchain-based payment and settlement systems can facilitate faster and more secure payments between parties in the supply chain, including suppliers, manufacturers, distributors, and customers. By using blockchain, payment, and settlement transactions can be conducted in real-time, reducing the need for lengthy payment cycles and reconciliations. Furthermore, blockchain-based payment and settlement systems can reduce the risk of fraud and errors in payment processing, providing greater security and trust for all parties involved.

Another important application of blockchain for payment and settlement in SCM is the ability to automate payments using smart contracts. Smart contracts are self-executing digital contracts that automatically enforce the terms of an agreement between parties. By using smart contracts, payment, and settlement processes can be automated, reducing the need for manual intervention and increasing efficiency. For example, a smart contract can be used to automatically release payment to a supplier once the goods have been received and verified by the buyer. This not only reduces the risk of errors and fraud but also enables faster payment processing and improved cash flow management for all parties involved in the SCM.

3.5. Customer engagement and loyalty

Blockchain can also be used to enhance customer engagement and loyalty in SCM. By providing transparency and traceability throughout the supply chain, customers can have more trust in the products they purchase. This can be particularly important in industries where there are concerns about sustainability or ethical sourcing. By using blockchain, companies can provide customers with information about where their products come from, how they were produced, and who was involved in the process. This can help to build brand loyalty and differentiate companies from their competitors.

In addition, blockchain can be used to create loyalty programs that are more transparent and secure. With traditional loyalty programs, customers earn points or rewards for their purchases, but there is often little transparency about how those points are earned or how they can be redeemed. Blockchain can enable companies to create loyalty programs that are more secure, transparent, and flexible. By using blockchain, companies can create tokens that are redeemable for goods or services, and customers can track their rewards and redeem them more easily. This can create a more engaging and rewarding customer experience, which can help to build long-term loyalty and drive repeat business.

3.6. Compliance and regulatory reporting

One of the challenges faced by supply chain participants is ensuring compliance with various regulations and reporting requirements. Blockchain technology can help overcome these challenges by providing a tamper-proof and auditable ledger of transactions. For instance, companies can use blockchain to track the provenance of goods, ensuring that they are sourced and transported in accordance with legal and ethical standards. Additionally, smart contracts can be used to automate compliance reporting and auditing processes, reducing the burden of compliance management for supply chain participants.

Blockchain can also facilitate compliance with regulatory reporting requirements by providing a single source of truth that can be shared among all participants in the supply chain. For example, customs authorities can use blockchain to access real-time data on the movement of goods, ensuring that they are properly declared and accounted for. Similarly, financial regulators can use blockchain to monitor transactions and enforce compliance with anti-money laundering (AML) and know-your-customer (KYC) regulations. By leveraging blockchain's ability to provide secure and transparent data sharing, supply chain participants can achieve greater compliance and reduce the risk of penalties and fines.

A tabular summary of the application of blockchain for compliance and regulatory reporting in SCM is provided in Table 6.

Application	Description
Provenance tracking	Use blockchain to track the origin of goods, ensuring compliance with legal and ethical standards
Smart contracts	Automate compliance reporting and auditing processes
Data Sharing	Use blockchain to provide a single source of truth for all participants, facilitating compliance with reporting requirements
Customs monitoring	Customs authorities can use blockchain to access real-time data on the movement of goods
AML/KYC compliance	Financial regulators can use blockchain to monitor transactions and enforce compliance with AML/KYC regulations

4. Future Directions

The field of blockchain technology in SCM is still in its early stages, and there is a lot of room for future research and development. One potential direction for future research is to explore the use of blockchain technology in combination with other emerging technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI). For example,

the combination of blockchain and IoT can enhance the transparency and traceability of supply chain processes, while the combination of blockchain and AI can facilitate real-time decision-making and optimization. In addition, with the proliferation of blockchain networks, it will be important to develop standards for interoperability among these networks to ensure seamless integration of blockchain-based supply chain applications across different platforms. Blockchain technology is currently facing scalability issues, particularly in terms of transaction processing speed and storage capacity. Future research could focus on developing solutions to address these scalability challenges. Moreover, the adoption of blockchain technology in SCM requires appropriate governance and regulatory frameworks to ensure legal compliance and protect the rights of all stakeholders involved in the supply chain. Future research could explore the development of such frameworks. Besides, blockchain technology has the potential to contribute to sustainable SCM by providing greater visibility and traceability of products and materials. Future research could explore the application of blockchain technology to enhance sustainable practices in SCM. The success of blockchain technology in SCM depends on the adoption of the technology by all stakeholders involved in the supply chain. Future research could focus on identifying barriers to adoption and developing strategies to encourage greater user adoption of blockchain-based supply chain applications. As blockchain technology is applied in SCM, it is important to consider the ethical implications of its use, particularly regarding privacy, security, and the distribution of benefits across supply chain participants.

5. Conclusions

In this work, we provided a comprehensive review of the business applications of blockchain technology in SCM and have identified promising future directions for its use. We have highlighted that blockchain technology can provide numerous benefits to SCM, such as increased transparency, improved efficiency, reduced costs, and enhanced trust and security. The current applications of blockchain technology in SCM have been discussed, including tracking and tracing of goods, verification of product authenticity, and automating supply chain processes. The benefits and challenges of implementing blockchain technology in SCM have also been examined, emphasizing the need for businesses to carefully consider their specific needs and circumstances before adopting blockchain technology. We have identified several promising directions for research and development in blockchain technology for SCM. These include the integration of artificial intelligence and machine learning, the use of smart contracts, and the development of new blockchain-based business models.

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