

Research Article

Ensuring Supply Chain Transparency by Deploying Blockchain-Enabled Technology: An Overview With Demonstration

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It is nowadays quite challenging to manage and control the supply chain concerning transparency, traceability, and zero-trust security. Digital technology such as blockchain has shown promising features to ease the global supply chain for tracking, tracing, and authenticity. This study critically examines the potential of blockchain technology and smart contracts to manage global supply chain sustainability. It also analyzes the inherent opportunities, benefits, and common barriers to deploying blockchain in the supply chain. Moreover, an overview of blockchain technology and its application in the various industries' supply chain management is illustrated in this study. Furthermore, an application demo related to blockchain in the supply chain is provided within the scope of this study with the view to demonstrating how various transactions in the supply chain are executed with higher authenticity. The study is concluded with several future research propositions and directions that may provide insight into overcoming current challenges and the adoption of blockchain for the supply chain.

Keywords: blockchain; blockchain demo; smart contracts; supply chain management; zero-trust security and transparency

1. Introduction

Digitalization and digital technologies, as major transformational forces in the current business landscape, have revolutionized the operational and innovation management processes while driving firms to reinvent their ways of conducting business [1–3]. Theoretically, research on digital disruption and innovation is inciting existing theories to conceptually develop interdisciplinary frameworks by capitalizing on digital transformation and organizational change processes. Such a rise in the economic and knowledge landscape has strengthened a crucial need for novel theorizing

on digital innovation management which can draw on disruptive technologies [4]. In such an emerging digital economy, blockchain technology appears to radically innovate the whole supply chain and business models by providing several opportunities for new value creation [1, 4, 5].

Blockchain has increasingly gained ground in literature on e.g., strategy, innovation, entrepreneurship, and digital economy and significant attention from different industries e.g., energy supply chain, tech-startups, financial institutions, public sector, and food and luxury items supply chain. Seminal studies in the literature have presented a set of definitions and concepts in different contexts, considering

blockchain with different labels and purposes. For example, Treiblmaier [6, p. 547] defined blockchain as “a digital, decentralized and distributed ledger in which transactions are logged and added in chronological order with the goal of creating permanent and tamper-proof records”. As such, blockchain eradicates the exploiting role of middlemen, thereby minimizing transaction costs and time [4, 7, 8]. The encrypted transaction characteristics of blockchain and a distributed process of authorizing transactions and building blocks make it immutable with security and verified platforms on cryptographic algorithms network [8–10].

To address the issue of authorizing transactions in the logistics industry, a blockchain-based solution named ‘TradeLens’ formerly known as Global Trade Digitization (GTD) led by Maersk and IBM allows real-time information to be shared and digital collaboration in a decentralized way across the whole network [11]. Similarly, within the retail logistics industry, GSI, a global business communication standards organization that maintains logistics and transportation-related centralized identity repositories, started a collaboration with IBM and Microsoft to leverage its standardized processes in their enterprise blockchain applications for supply chain network users. The aim of such collaboration was not just to increase data integrity and zero-trust security [12, 13] between parties but also to reduce data duplication and reconciliation [9].

Over the past years, blockchain has started to be used across sectors as a general-purpose technology [14]. It has the potential to not only disrupt policies and services but also to constitute a new institutional technology of governance that can improve current organizational processes [15]. Thus far, the overwhelming majority of blockchain research has concerned financial transactions, the digital economy, and cryptocurrency. However, there is a growing potential in analyzing the use of blockchain technology in healthcare [16], the energy sector [17], and other public services such as land registries, innovation ecosystems, real estate industry, pension, and income-based benefits, and tax administration [18]. Furthermore, existing research and applications on the blockchain have been focusing on its implementation in supply chain management (e.g., [8], real estate development [18–20]), fashion retailing (e.g., [21], hospitality [22]), pharmaceutical supply chain (e.g., [23, 24] and agri-food industry [25]).

Blockchain technology has the potential to disrupt the existing industrial supply chains. Blockchain in the supply chain has gained a great level of attention across all industrial sectors due to its verified and immutable transactions in a distributed network which eliminates intermediaries [26]. Similarly, smart contracts, conceptualized by Szabo [27], became pertinent in supply chains as they offer automated shared rules of exchange and predefined functions among different actors [28]. Therefore, several researchers (e.g., [29–32]) have delved into different applications of blockchain in supply chains. There remain several challenges of traceability and transparency in global supply chains as several partners with different sizes from upstream to downstream function in a different manner. Therefore, the advent of blockchains has been considered a solution for addressing such challenges.

Based on the above circumstances, the objectives of this study are to present the basic concept of blockchain technology and its application in various supply chain segments. In addition, various benefits or opportunities of blockchain technology in the supply chain are explained within the scope of this study. Moreover, different bottlenecks or barriers to deploying blockchain in supply networks are also stated with necessary explanations. Furthermore, a demo is presented to explain how the blockchain smart contracts are worked to provide necessary authentication services in the wider supply network.

The rest of the article is organized as follows: Section 2 explains relevant literature in the field of blockchain application to various business sectors, while, Section 3 outlines the fundamentals of blockchain technology. Specific application of supply chain in the blockchain is illustrated in Section 4, where opportunities, potential benefits, and challenges are discussed too. In Section 5, the application of blockchain in the various industries’ supply chains is described, whereas, Section 6 presents a blockchain-enabled smart contract framework for the supply chain. A demo of blockchain-enabled smart contracts in the supply chain is highlighted in Section 7. The article is concluded in Section 8 with proposed future works in the field of interest.

2. Literature Review

Blockchain offers transparency throughout the supply chains in different industries which enables quality through the visibility and accessibility of logistics information, thereby building a trustworthy environment in supply chain relationships [8, 33]. Different industrial sectors have employed and witnessed the transparency feature of blockchains such as transparent customer orders and services [34], minimizing the lengthy processes of verification and automating accounting services in the banking sector [35], expediting claims settlements, and improving fraud management [36], transparent document exchange in the maritime supply chain [26], renewable energy sector [37–39], preventing food issues in the food supply chain [40–44] enabling reporting in the financial sector [45], and secure and transparent pharma and healthcare [46–48].

As blockchain runs beyond bitcoin, though having roots in cryptocurrency [49], its distributed ledger aspect functions on a pile of technologies containing the internet as an infrastructure to contain transaction records on established consensus rules [50, 51]. Blockchain technology offers several solutions based on transparency, zero-trust security, reliability, and immutability across industries which makes it unchallengeable and trustworthy between parties [8, 9, 52–55] and facilitates collaboration [56–58]. It has been offering infrastructures to collaborate effectively and organize transactions in several industries, e.g., from payment handling in the financial and insurance industry to song tracking in the music and locating bills of lading in the transportation and logistics industry [59, 60]. Since blockchain, regardless of expectations in partner’s behavior, enables trust among them, several multinational corporations, start-ups, and venture capitalists are drawing their attention

toward it by investing a good amount of resources to develop several applications powered by blockchain [60].

In the recent literature (e.g., [51, 61, 62]), two dimensions (i.e., novelty and complexity) are identified that guide how a foundational technology and its business use cases evolve in an ecosystem. The novelty dimension of a technology which represents the degree to which a certain technology is new to the world determines the efforts required to ensure its tendency of solving certain problems. While complexity represents the level of ecosystem coordination wherein the number and diversity of ecosystem participants working together evolve to produce value for the customers. Thus, the novelty of blockchain is providing the foundation for new ecosystems to shape up for collaboration and delivery throughout the value chain [63]. However, significant institutional changes will be required to achieve the scalability and impact of blockchain because blockchain also brings certain challenges for adoption.

The growing experimentation with blockchain technology in both the private and public sectors has revealed several technical and organizational challenges [64, 65]. These include the lack of efficiency in sharing data from mobile devices, scalability and interoperability issues, and privacy and zero-trust security concerns, particularly in the context of GDPR [66–68]. Exemplary use cases for blockchain that are often described include uses for various supply chains [69] and transfer of contracts, applications that limit the need for a trusted third party (such as a bank). Financial instruments such as payments, trading records, etc., can also be developed through blockchain which helps to avoid adversarial behavior and certain consequences, for example, extra costs, forgeries, and false disputes [70]. In addition, blockchain can also be used for public and legalistic activities where citizens' data is handled [71].

Furthermore, prior research also remains fragmented toward the use and goals of blockchain, for instance, creating a decentralized environment without control of transactions of any third party is considered a main goal of blockchain. While some studies highlighted that blockchain functions as an enabler of cloud computing and immutable databases [72–74], similarly, some consider it as a global platform for executing smart contracts [75]. However, according to recent research, only 1% of CIOs reported blockchain implementation, and only 8% of respondents get involved in short-term planning and pilot planning [76, 77]. Table 1 presents the most recent and relevant studies on blockchain in different sectors explaining their findings and contributions.

3. Fundamentals of Blockchain Technology

Blockchain became popular when Nakamoto [84] published an article on distributed ledger technology (DLT), 'Bitcoin—A peer-to-peer electronic cash system' which aimed to transform the transactions and businesses, thereby attracting both public and private sectors' attention. Blockchain's central point lies in key elements of decentralization, transparency, autonomy, immutability, and anonymity. The transactional data is chronologically

combined in a block while having an encrypted boundary. Each block joins a new block with each transaction, thereby creating a chain which is called a blockchain. Once a new block is added, an updated chain of blocks is then distributed to all nodes on the chain. It helps in tracking each transaction as well as the original blockchain. In other words, each block holds a cryptographic hash of the previous block, transaction data, and a timestamp. Therefore, it becomes difficult to modify or change data because once recorded, the data in any specified block cannot be changed retroactively without altering all following blocks.

As blockchain is at the heart of the Bitcoin protocol, it carries a series of blocks containing data, including the hash of the block which connects to the next block. A blockchain is a chain of blocks that contains certain information about transactions and data (Figure 1). Such repeated process of blocks makes it difficult for ones who want to modify some blocks in the middle as it requires the modifications in each block. As if one block is modified, the next blocks would then carry a different hash [85]. As blockchain eliminates the central authority or a third party, its distributed ledger and logs of records enhance transparency and minimize the chances of manipulation. The timestamp and a hash function of blockchain cryptographically link different blocks together wherein the transactional data is stored inside the blocks.

For example, a buyer and a supplier who want to conduct a transaction on the blockchain should be a part of a blockchain peer-to-peer network and need to have a digital wallet that functions like a bank account that contains cryptocurrencies and is associated with the public addresses and private keys. Public addresses can be published on the blockchain peer-to-peer network or web-based platforms where senders can use them to send cryptocurrencies. While, the private keys are used by the owners of digital wallets to verify the transactions, similar to what we do in our bank apps. A block in a blockchain also has a hash function similar to fingerprints which is difficult to temper while having unique characteristics. Such hash identifies a block and all of its data. So once the block is created, its hash is calculated. This means any changes inside the block will also affect its hash and it will change the hash as well. So actually, hash helps you to detect changes in the blocks. However, there are some security concerns yet. There is still a risk for blocks to get tampered with. Therefore, a Proof-of-Work (PoW), Proof-of-Stake (PoS), and Proof-of-Authority (PoA) have been introduced (Table 2) that can significantly mitigate risks of tampering blocks [85], as well as keep the information reliable, valid and secure in the ledger. Thus, with the three significant properties for example, decentralized, verified, and immutable (Figure 2), blockchain becomes a trust and transparent technology offering several solutions to supply chains and other industries [31].

PoW is an apparatus that resists creating new blocks rapidly. If one tampers with a block in the blockchain, the recalculation of PoW for all blocks becomes necessary. Such kind of security strengthens the blockchain [86] where all users on the blockchain compete to validate transactions. However, major drawbacks of such a protocol include high

TABLE 1: Current research on blockchain adoption in different disciplines.

Authors	Objectives	Methods	Key findings	Contributions
Wang et al. [47]	To enhance information exchange efficiency, an AI and DAG-enabled blockchain approach is proposed, ensuring a secure and efficient environment for medical IoT data exchange	Simulation and performance evaluation	An information exchange approach based on AI and DAG-enabled blockchain improves the efficiency of information exchange in medical IoT by optimizing the consensus algorithm and introducing a disease category-based tip selection algorithm	Provides a secure and efficient environment for information exchange in medical IoT, enhancing the speed and reliability of data transactions
Maythu et al. [78]	This study explores the factors that influence blockchain diffusion in tourism and blockchain innovation diffusion in the tourism sector	Qualitative-Semi-structured interviews of tourism organizations in the US and Europe	Blockchain offers competitive advantages despite limited success in tourism use cases. Developed a conceptual framework and propositions for blockchain diffusion in tourism	Provides insights into the motivators, drivers, challenges, and barriers of blockchain adoption in tourism. Offers a research agenda for strategic implementation of blockchain
Obidallah et al. [79]	To investigate how the Technology Acceptance Model (TAM) applies to blockchain adoption among Saudi Arabian construction companies	Cross-sectional data collection, quantitative research approach, PLS-SEM analysis	Attitude toward adopting blockchain and perceived ease of use are strong predictors of behavioral intention to adopt Blockchain. Top management support influences adoption indirectly through perceived usefulness	Provides insights into the internal factors influencing blockchain adoption in the construction industry, highlighting the role of top management support and the applicability of TAM
Rai et al. [80]	To analyze the challenges, scope, and potential solutions of integrating blockchain technology with IoT, focusing on nuclear energy applications	Comprehensive analysis, development of a secure data management framework, and exploration of cryptographic, mathematical, and algorithmic perspectives	Blockchain's immutability and transparency ensure data integrity, while IoT's real-time data collection enables system monitoring. Challenges such as scalability, security, and privacy arise from blockchain's decentralized nature. An integration framework and solutions are proposed to address these issues, along with an IoT architecture for secure blockchain-based data management in the nuclear energy sector	Provides a secure data management framework incorporating encryption, integrity verification, and robust data flow architecture. Highlights the potential and challenges of blockchain-IoT integration in nuclear energy
Huang et al. [81]	To enhance the ecological governance system and capabilities in Qinghai Province using blockchain technology	In-depth analysis of basic advantages of blockchain, development of a blockchain-based ecological governance framework, and empirical analysis	Blockchain technology can significantly improve ecological governance by enhancing transparency, efficiency, and trust. Specific strategies include resource utilization management, pollution control, and ecological alliance chain platforms	Provides innovative strategies for ecological governance in resource-based cities, highlighting the potential of blockchain technology to address traditional governance challenges
Yadav et al. [82]	This study identifies and comprehends the challenges of adopting blockchain technology in the manufacturing sector to improve sustainable standards, focusing on the rubber industry	Comprehensive literature review, expert discussions, data collection from 15 professionals, and analysis using CoCoSo and fuzzy DEMATEL methodologies	High initial investment cost and lack of digital skills are the top challenges in blockchain adoption. The study provides a roadmap for making the manufacturing supply chain sustainable	Offers a detailed analysis of the challenges in blockchain adoption, prioritizes them, and explores their cause-and-effect relationships. Provides insights for overcoming these challenges to promote sustainable practices in the manufacturing supply chain

TABLE 1: Continued.

Authors	Objectives	Methods	Key findings	Contributions
Rashid et al. [42]	This study employs blockchain technology to transform the traditional agri-food supply chain in Bangladesh, focusing on increasing transparency, enhancing efficiency, and improving profitability for farmers	Development of a blockchain-based smart contract on the Ethereum blockchain network, creation of a web application, performance analysis, and testing	The blockchain-based model enhances transparency, traceability, and accountability in the agri-food supply chain, reduces dependency on intermediaries, and increases profit margins for farmers	Provides a comprehensive blockchain-based agri-food supply chain model, introduces roles for system administrators and inspection teams, includes government oversight for price control, and demonstrates the practical application and scalability of the model
Tang et al. [43]	To assess the applicability and efficacy of blockchain and IoT technologies in transforming food traceability and addressing issues like food fraud and contamination in African agricultural food supply chains	Comprehensive literature review, and feasibility analysis using the TELO framework (technical, economic, legal, operational)	Blockchain and IoT technologies have significant potential to enhance food safety and transparency in African food supply chains. However, challenges related to scalability, cost-effectiveness, and regulatory frameworks need to be addressed	Provides a roadmap for future research and strategic implementation efforts, highlighting the importance of adapting blockchain and IoT technologies to fit the diverse socio-economic and infrastructural realities in African countries
Rejeb et al. [39]	To systematically examine the integration and impact of blockchain technology within the renewable energy sector, identifying current research trends and potential future directions	Comprehensive bibliometric analysis of 390 journal articles	Blockchain technology has significant potential to enhance energy efficiency, enable decentralized trading, and ensure transaction transparency in the renewable energy sector. Key thematic areas include blockchain's integration with smart grids, its role in electric vehicle integration, and its application in sustainable urban energy systems	Provides a comprehensive overview of the emerging trends and thematic shifts within the nexus of blockchain technology and renewable energy. Sets a precedent for future interdisciplinary research, bridging theoretical insights with practical applications to fully harness the potential of blockchain in the renewable energy sector
Haryani et al., [37]	To propose a blockchain-based solution for Indonesia's electricity grid to enhance end-to-end traceability, real-time data access, and tamper-proof records for the renewable energy certificate (REC) system	Interviews with energy stakeholders, blockchain model development, prototyping, and evaluation of its efficacy	Blockchain technology can revolutionize the Indonesian REC market by improving security, traceability, and promoting stakeholders' trust. The proposed framework introduces a semifungible REC token for secure issuance, trading, and verification	Provides a scalable model that can support Indonesia and global green energy adoption and sustainable living. Addresses current system limitations and offers a comprehensive blockchain-based traceability framework for the Indonesian REC scheme
Sayma et al. [44]	To propose a blockchain-based agri-food supply chain using a private Ethereum blockchain network to detect the provenance of price hikes	Development of smart contracts, creation of a decentralized application (dApp), and security and vulnerability assessment	The proposed system demonstrated greater transparency, traceability, reliability, speed, security, and cost-efficiency compared to conventional systems. It effectively traces the origin of corruption in the supply chain, providing a more straightforward means to tackle concerns related to price hikes	Provides a comprehensive blockchain-based solution for the agri-food supply chain, ensuring immutability, transparency, and ease of tracking and monitoring. Offers a scalable model that can be adapted to various goods and industries
Padma and Ramaiah [48]	To propose a blockchain-based solution for secure information sharing in pharmaceutical supply chain management (PSCM)	Implementation of the blockchain-based solution in three phases: Registration, pharmaceutical product circulation, and secure payment. Security analysis and performance metrics evaluation	The proposed framework effectively mitigates impersonation and collusion attacks. It demonstrates improvements in transparency, traceability, security, and efficiency compared to traditional PSCM frameworks	Provides a comprehensive blockchain-based solution for PSCM, ensuring data provenance, transparency, and integrity. Offers a scalable model that integrates with traditional PSCM systems through APIs and middleware

TABLE 1: Continued.

Authors	Objectives	Methods	Key findings	Contributions
Polcumpally et al. [83]	To critically examine the scholarly work conducted in blockchain (BC) governance, focusing on trust as a foundation for BC governance	Thematic systematic literature review using the SALSAs (Search, Appraisal, Synthesis, and Analysis) technique	BC technology replaces cognitive attribution of trust with material and human-independent code. Further research anchored to the 'trust' concept is required in building BC governance structures	Provides a comprehensive review of BC governance literature, identifies gaps, and proposes future research directions. Highlights the potential of BC to revolutionize business operations by improving transparency, efficiency, and security
Haq et al. [65]	To explore the required leadership competencies for successful blockchain technology (BCT) implementation in public sector organizations from a sensemaking perspective	Multiple case study design, semistructured interviews with representatives of Finnish public sector organizations, and analysis using NVivo14	Leaders identify cues for digitally transforming their organizations through blockchain by leveraging curiosity and rational vision. They interpret these cues through technological understanding and exploring different technological solutions. Finally, they enact blockchain by connecting its outcomes with organizational processes and goals. The study also identifies a dark side of BCT, including overly optimistic expectations and technological dependencies	Provides a framework for public sector leaders to use when considering blockchain adoption. Contributes to the literature on leadership competencies by applying sensemaking to the study of BCT. Highlights the importance of curiosity, rationality, technological understanding, and exploring different technological solutions for successful blockchain implementation
Shahzad et al. [33]	To develop an explanatory framework for supply chain (SC) resilience and operational excellence using blockchain technology	Rigorous analysis of recent literature, existing industrial cases (food SC, diamond SC, EV battery SC, blood SC), and a reference architecture implementation in forest SC	Blockchain enhances SC resilience and operational excellence by providing transparency, traceability, real-time information sharing, process efficiency, and security. The reference model demonstrates increased process efficiency through data safety, transparency, and traceability	Provides a comprehensive framework for blockchain adoption in SCs, highlighting its potential to address traceability challenges and develop operational excellence. Offers a reference implementation in the forest industry, demonstrating practical applications and benefits of blockchain technology
Juszczyk and Shahzad [38]	To investigate the level of trust and maturity of blockchain technology implementation in the renewable energy industry and provide a roadmap for blockchain adoption	Blockchain maturity questionnaire, semistructured interviews with upper management professionals from the renewable energy industry	The study reveals the state of know-how about blockchain, the main benefits and bottlenecks associated with its implementation, and the willingness to integrate this technology in future operations. The analysis identifies decentralization, smart contracts, and traceability as key benefits, while scalability, lack of regulations, and technological maturity are major barriers	Provides a comprehensive overview of blockchain technology's principles, applications, and prospects in the renewable energy sector. Offers a roadmap for blockchain adoption, highlighting the need for multi-sector involvement and supportive regulations

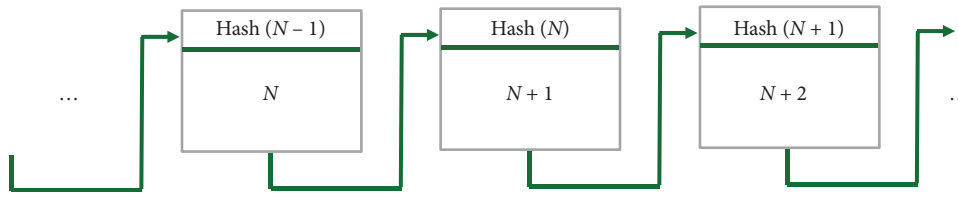


FIGURE 1: The basic architecture of blockchain (adapted from [85]).

TABLE 2: PoW versus PoS versus PoA.

PoW	PoS	PoA
All users can compete to verify	You ‘stake’ several tokens	Relies on a limited number of validators
Bitcoin uses POW to ensure	Small groups of nodes validate transactions	A modified form of POS
High energy consumption and processing time—51% attack	Low cost and low energy consumption	Fits well with consortium networks
	Users with a larger share of the system	Relies on a limited number of validators

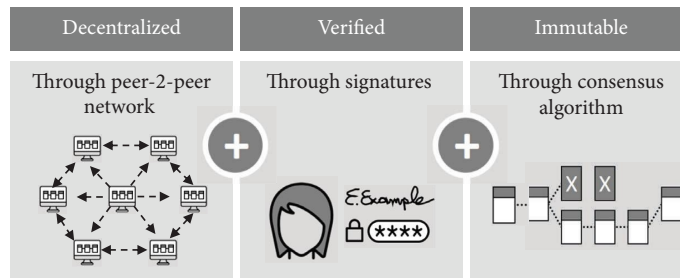


FIGURE 2: Properties of the blockchain (adapted from [31]).

energy consumption and longer processing time. Not just that, but if any single entity obtains more than 51% of the computing power, they could theoretically diverge the blockchain to be whatever they want it to be, which is known as a 51% attack (e.g., [87]). PoS is fundamentally different. Instead of computational power to verify and expand the blockchain, it “stake” several tokens (not necessarily a cryptocurrency) on the blockchain network. This is normally done by creating a “node” that facilitates participating in the blockchain ecosystem. A node could be a personal computer or a network of computers.

Regarding the transactions, in PoS, only a small number of nodes who have a dedicated power or responsibility to maintain a public ledger can verify transactions as it has to do with the proportion of cryptocurrency tokens that are associated with that node [87]. This also means that the users with a big share of the system wealth have more power to provide trustworthy information and can validate transactions [86, 88]. PoA, however, represents a consensus mechanism that depends on a few numbers of trustworthy nodes, in other words, block validators that are preapproved. PoA is considered as an adapted version of PoS, wherein the identity of validators to some extent is not more important than the role of stake which is quite important. These validators verify selected transactions based on certain rules defined among them. PoA fits well with consortium blockchains where certain preselected authorities have permission to regulate and control the data which is added to the public registry [86, 87].

4. Blockchain Technology in Supply Chain Management

4.1. Opportunities and Potential Benefits of Blockchain in Supply Chain Management. Blockchain technology can transform the supply chain with three important use cases such as traceability, transparency, and tradeability. Supply chain stakeholders are nowadays more demanding to know the status of the products they buy. In this situation, blockchain can help companies to understand their supply chain and engage consumers with real, verifiable, and immutable data [89, 90]. This verification process supports to enhance product traceability that ultimately reduces counterfeiting and manages to streamline product recalls. Often, companies need to recall their products or raw materials to prevent injury or illness. This recall of consumer products or ingredients negatively affects companies through losing sales, replacement costs, and lawsuits. Recall of products can be more efficient if it is possible to locate the affected products as quickly as possible. Blockchain technology can be considered in this scenario to facilitate faster and more efficient recall [89, 91].

In addition to product traceability and recall, counterfeiting is also an important concern in global supply chain management. It is estimated that online counterfeiting was responsible for 323 Billion USD in the year 2017 globally [92]. Blockchain technology enables to overcome such counterfeiting by verifying a product

from source to consumer accurately and ethically. Not only to products, but counterfeiting is also common among the certifications and official identifications of supply chain documents. This technology not only provides physical products but also supports tracking of any digital product throughout its life cycle. It is then ensured sustainable and ethical production and consumption of any commodity.

Alongside product traceability, blockchain provides traceability to supply chain management, which is considered one of the top use cases. In general, traceability is one of the top use cases to improve the operational efficiency of the supply chain through better mapping and visibility. Blockchain, which is a DLT, can increase trade volume by 15% if the traditional tracking processes are replaced by this technology [93]. It can track the advancement of goods, goods' past locations, and record travel history. Such goods/assets tracking support goods authenticity from source to the end consumers. This transparency through process tracking gives goods manufacturers bird-eye views into their value chain and protects counterfeiting.

Asset tracking offers a real-time update of an asset, whether it is physical or digital. Smart contracts are usually used to implement these asset tracking processes through the Ethereum blockchain. There are many useful applications of asset tracking. For instance, in the pharmaceutical industry, blockchain can provide improved compliance and report for medical devices, patients' reliance on prescription drugs, and other consumer goods. It supports efficient pharmaceutical supply chain management by avoiding under or overstocked medications [89].

The third use case of blockchain deployment in supply networks is tradeability. This tradeability is considered a unique blockchain offering for marketing. By deploying blockchain, an asset can be split into shares, which are tokenized to digitally represent ownership. These tokens are mutually tradable without changing the hands of the physical asset. These fractional shares are allowed to represent value and can be traded similar to the stock exchange market. In this trading process, blockchain enables accurate license services using automated smart contract payments. It provides dispute-less supply chain transactions by the potential and unique tracking of the ownership records for assets such as real estate, automobiles, digital assets, etc.

From Figure 3, it can be noticed that by using blockchain, supply chain stakeholders can achieve several benefits such as a distributed ledger system, real-time visibility, accessibility, trust, and security. In the case of a distributed ledger system, blockchain offers secured transactions. It provides real-time visibility by offering real-time transfer of documents from one node to another within the network. In line with accessibility, blockchain offers secured information access between the network partners in the supply chain. It also provides trust and security that promotes reliability, motivation, and confidence among the stakeholders. Trust is ensured through establishing credibility between the business partners, while security is maintained through codified rules.

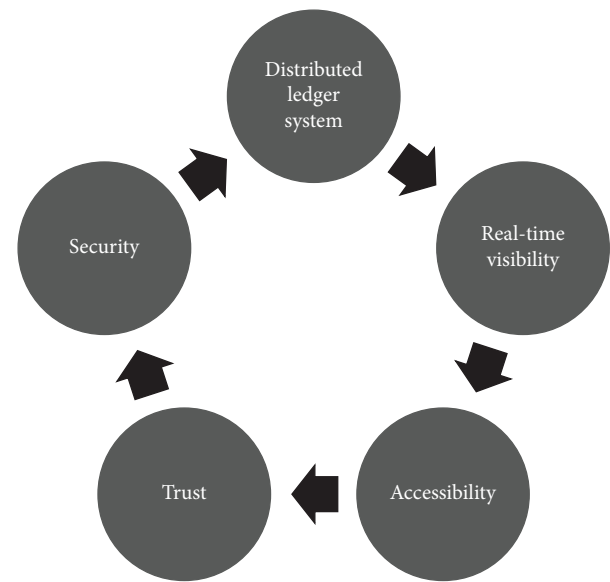


FIGURE 3: The supply chain benefits from using blockchain technology.

The implementation of blockchain in supply chain management supports achieving improved forecasting and reducing process bottlenecks. It provides supplier reliability by providing in-built digital currency-backed transactions, rapid financial transaction fees, and lower goods lead-time and cost [94]. The application of blockchain presents the facility for any company, whether public or private, to establish a secured and trusted network, where partners can share valuable information and exchange knowledge. This sharing system is codified securely within the network, and no one can change its content [95].

4.2. Challenges of Deploying Blockchain in Supply Chain Management. Despite the obvious benefits of blockchains in supply chains and logistics, there is a large number of barriers and challenges for organizations to deploy blockchains in their supply chains. Several barriers to blockchain technology have been reported in recent research (e.g., [31]). Since blockchain is a decentralized technology and has no governing body as such, there remains confusion about who owns it. There is no facet to being in charge and being in charge means developing and offering the technologies and the application, making sure that the legislation is followed by the application, and also by the users, and generally leading the agency.

Kouhizadeh et al. [51] identified the four most common barriers namely technological, organizational, internal, and external environments. Technological barriers contain challenges related to blockchain technology, such as security, accessibility, and immaturity. A lack of technological capabilities exists in most companies. Organizational barriers include management commitment, culture, and policies. While, environmental barriers can be divided into internal and external challenges; internal challenges consist of information disclosure, collaboration problems, and lack of awareness whereas external challenges include government

policies, legislation, and ethical practices [96]. However, such barriers can be addressed by developing a corporate culture and communication between supply chain stakeholders.

The use of blockchain technology in supply chain management is not an easy task. There are still many challenges to this technology such as scalability and security problems that need to be overcome. This technology needs to overcome challenges or hurdles, which is very common in implementing any kind of new technology. These challenges can be identified from various supply chains management perspectives, such as legal aspects, standards, methodologies, integration, and financial issues. Figure 4 presents the major challenges faced by blockchain in implementing it in the global supply chain network.

Figure 4 shows that the challenges of using blockchain in the supply chain are categorized mainly as legal status, standards, methodology, integration, and financial aspects. In the case of legal rules, the accompanying challenges are to the imposed rules and regulations of a country, whether in the form of regional restrictions and/or currency issues. Any changes to the rules and regulations of a country or a region will directly affect blockchain technology, which may need to adapt and adjust its operations according to the changed rules and regulations. For standards, the challenges can be following the international and organizational standards. The challenges related to the methodology are to managing the vast amount of data and maintaining its privacy, encryption, and security.

For the integration issues, blockchain faces several challenges such as cross-industry collaboration, conflict management, and change management [97]. There is also the challenge of integrating blockchain technology with existing technologies employed by the supply chain stakeholders. Usually, it is quite hard to change an existing technology to adopt new technology in supply chain systems, and it is expensive [98]. Challenges related to the financial aspect concern the acceptability of cryptocurrency, financial transactions, and currency replacement. Considering all such challenges, there is also a need to analyze the risks and rewards of blockchain technology to be successful in the global marketplace.

In addition to the above-mentioned challenges, there are additional technical barriers, which need to consider before deploying blockchain in supply chain management. Some of the barriers are presented in Table 3.

5. Application of Blockchain in Various Industries Supply Chain Management

There are many examples of applications or efforts which have endeavored to streamline the leverage of blockchain to improve the supply chain (e.g., IBM, Walmart, Maersk, and Provenance). The aims of implementing blockchain in the supply chain network are to solve the inherent complexity of diverse global supply chain relationships using an incorruptible distributed digital ledger of transactions that can be programmed to record anything of value. It offers a verification option, where every participant within the

supply chain can view a history of a database of critical record-keeping items in a digital cryptocurrency in which these historical records cannot be deleted or modified even after the events are closed. There are different industrial segments, where blockchain can be easily deployed for mutual benefits and some of the segments are stated as follows:

- (a) *Pharmaceutical industry supply chain:* For the pharmaceutical industry, blockchain can support managing complicated supply chains by providing ways to track medical products, such as drugs, devices, tools, etc. In the pharmaceutical industry, ingredients of drugs might come from third-party manufacturers or suppliers, which are then produced in the base factory as finished drugs that are then labeled and branded. In this production chain, drug producers are required to control all the associated processes in the supply chain to guarantee proper handoff of intermediate goods and final product labeling. Pharmaceutical supply chains need to follow strict regulatory standards. Blockchain technology could be one way out to manage the pharma supply chain through immutable data management by reducing driving costs, better compliance through trust and transparency, and enhancing customer experience through trust and transparency.
- (b) *Wood industry supply chain:* In the wood industry supply chain, blockchain technology can be used for the real-time traceability of wood products from the tree to the final user. This traceability is ensured by integrating the information related to the physical and digital documents with Radio Frequency Identification (RFID) architecture, which is an online information system [127]. This online information system ensures safer traceability through the blockchain to the entire forest wood supply chain from standing trees to the final product passing through the tree cutting and sawmills process. Blockchain technology is integrated with different kinds of Internet of Things (IoT) open-source devices and tags (e.g., RFID, QR codes, and sensors) to aim the forest operations to collect and store in centralized database information (e.g., species, date, position, densitometric, and commercial information) [99].

The tracking process of the wood supply chain works by the implementation of automated identification systems that establish a link among the wood products and a database of the wood products and processes it undergoes [128]. Blockchain is a process to keep records revealing the trail of input from suppliers to customers, which is an increasing interest in the forestry sector. Blockchain provides a single and tamper-proof system for digital tracking of timber in its supply chain. It is used to generate a digital ledger of transactions for trade in forest products that are impossible to manipulate. The

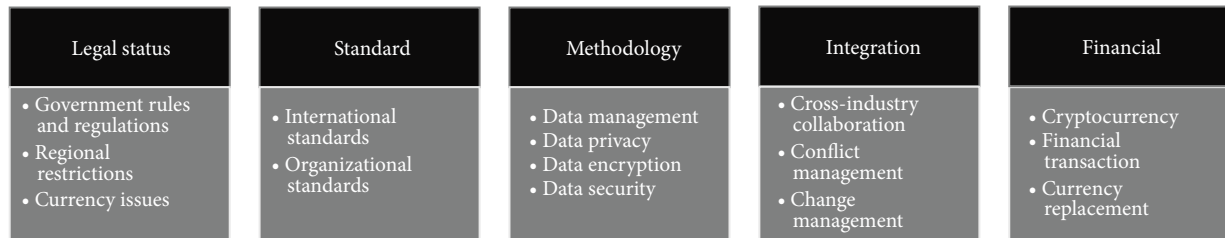


FIGURE 4: Challenges to using blockchain in supply chain management.

basic complexity of the wood supply chain is to understand, where the timber is sourced and to find out whether the source is legal or not. Blockchain transactions can be linked to the legal authorities to supervise legal timber to authenticate its legal status.

- (c) *Food industry supply chain*: In the food supply chain, the blockchain can be used as the information storage of food circulation such as the category, quantity, quality, origin, etc. In the food supply chain, relevant information such as where it was transported to or where it came from, helps stakeholders to improve the traceability management for food safety. All the necessary transactions in the supply chain are recorded and stored by one or several blocks within the blockchain to maintain transparent and open information, which can be searched and viewed by the stakeholders.
- (d) *Fishing industry supply chain*: The application of blockchain in the fish supply chain has the potential to improve people's lives and protect the environment through smart, sustainable fisheries. This revolutionary technology contributes to stamping out illegal fishing and human rights abuses in the fishing industry globally. This digital technology strengthens supply chain management by tracking fish from vessel to the supermarket. Global fishing industries are suffering from illegal, unreported, and unregulated fishing problems. In addition, they are also suffering from slave and child labor.

Nowadays, consumers are increasingly interested in traceable seafood that is not sourced from illegal fisheries or those that engage in human rights abuses. It is a common demand from the wholesale and retail seafood buyers that are asking for improvements in transparency and traceability to reduce the risk of their brands being associated with dubious and illegal activities. Blockchain technology in combination with RFID and QR codes can be used to capture information throughout the supply chain. Usually, the RFID tag is attached when a fish comes on board the vessel, which is registered automatically at various devices positioned at the dock and processing facility. Such tags or codes are potentially used to track the fish up to its final consumer all the way passing the retailers from source to end.

- (e) *Agriculture and food industry supply chain*: Integration of blockchain with various digital

technologies (i.e., QR codes, RFID, NFC, online certification and digital signatures, sensors and actuators, mobile phones, etc.) would be able to track the agriculture and food supply. The relevant tracking information of each of the stakeholders in the food chain, which are empowered by digital technologies is recorded and stored on the blockchain [114, 129]. The stakeholders of the food supply network, which forms a consensus between the stakeholders, validate the collected information from each transaction. The information from each of the blocks is validated and added to the transaction chain, which becomes a permanent record of the entire supply network.

Blockchain is considered a way out to transparent delivery of international aid, where each of the delivery processes is recorded and ensures efficient service in the wake of humanitarian emergencies [130]. The integration of blockchain with the IoT ensures real-time monitoring of the distribution logistics of spoilable food products. Such integrated technologies enable notification of problems in the food chain in real-time which helps to take fast action immediately. There is a rapid growth of blockchain in the food supply chain. For instance, Cargill Inc. uses blockchain to let shoppers trace their turkeys from source to the consumers [131]. Carrefour, a European food chain is using blockchain to verify standards and trace food origins in various categories, covering meat, fish, fruits, vegetables, and dairy products [132]. The downstream beer uses blockchain first time in the beer sector to tracking of beer from its ingredients to brewing methods [133].

6. Blockchain-Enabled Smart Contract Framework for Supply Chain

The smart contract is considered an important segment of blockchain application in various industrial segments. It enables the deployment and execution of different contractual agreements through programming logic [134]. The various contractual agreement in supply chain stakeholders may architecture through defining various data structures and functions. The unique feature of smart contracts in blockchain can improve operational performance through synchronization and automation of supply chain operations and accompanied processes [135].

The characteristics of smart contracts ensure the enforcement of legal contracts among the supply chain

TABLE 3: Various technical barriers to implement blockchain in supply chain management.

Number	Name of barrier	Brief description	Authors
1	Data security and confidentiality	It is quite difficult and complex to integrate blockchain with other available technologies such as IoT, RFID, sensors and actuators, robots, biometric data, big data, etc.	Tian [25]; Figorilli et al. [99]; Kim et al. [100]; Xu et al. [101]; Masood et al. [102]
2	Authorization issues	Pilot testing of the blockchain technology has not been sufficiently conducted, and a lack of validation could hinder its application and utilization	Akinradewo et al. [103]; Rejeb et al. [104]
3	Smart contract vulnerability	Insufficiently written contracts and mistakes made by people might have produced terrible results	Akinradewo et al. [103]
4	Accessibility	Blockchain technologies are very much essential to function in blockchain and to obtain accurate information from the real world	Hackius and Petersen [31]; Creydt and Fischer [105]; Gaurav [106]; Dudeczyk et al. [107]
5	High energy consumption	Proof-of-Work methods require enormous quantities of energy to operate, which affects the built environment in regarding demand, grid capacity, and emissions	Farooque et al. [108]; Petri et al. [109]
6	Lack of governance model	Applying blockchain in the supply chain to achieve information transparency and the immutability of the data might bring new challenges to the performance of supply chains	Xu et al. [101]; Tribis et al. [110]; Hald and Kinra [111]; Chen [112]; Mustafa et al. [113]
7	Lack of awareness and skilled workforce	The training platform for blockchain in supply chain is limited which is due to the general lack of awareness and skilled resources in this technology	Pearson et al. [45]; Kamilaris et al. [114]; Zhao et al. [115]
8	Lack of infrastructure	System stability depends on having enough server capacity, constant Internet access, and components of the supply. If connectivity is lost, the chain distribution system could malfunction	Singh and Kim [116];
9	Lack of standard rules and regulations	Lack of necessary policy-makers to capacitate the blockchain technology in supply chain stakeholders	Kim et al. [100]; Kamilaris et al. [114]; Arabsorkhi and Khazaei [117]
10	Needs to high computing power	Blockchain requires plenty of computing power which becomes a challenge if blockchain should spread globally in a similar manner to global supply chains	Hackius and Petersen [118]; Kshetri [119]
11	Interoperability	The most worrying issue of applications lies in the ability to connect to the surrounding ICT systems	Hackius and Petersen [118]; Anthony [120]; Shah and Raj [121]
12	Resistance to change	Adoption of new technology is challenging for traditional sectors, which are typically resistive to them	Mahmudnia et al. [122]; Hamma-adama et al. [123]
13	Reluctance to adopt	People's resistance to blockchain because it is a cutting-edge technology will keep it from being adopted and utilized	Rana et al. [124]; Wang et al. [125]
14	Information sharing obstacles	For some reasons, including market competitiveness, large corporations are unwilling to allow some of their information to be publicly available	Andrychowicz et al. [126]

stakeholders. In this consequence, smart contracts promote to automatic transfer of the various types of assets ownership, property, and value, which ultimately contributes to process design for logistics operations and services. Moreover, a smart contract enhances transparency and trust in the supply chain among the participating parties. It manages supply chain actors with less intermediation to its processes through re-engineering and automatic operational processes. Furthermore, a smart contract also enables a more transparent and automatic supply chain ecosystem by offering distributed records in a shared ledger instead of an exclusive centralized authority, which accelerates the overall operational efficiency of the supply chain process concerning cost minimization, efficient time management, and to enhance the scalability of the system [134].

Figure 5 displays the framework of blockchain-enabled smart contracts in the supply chain domain, where required communication is orchestrated by blockchain technology. From Figure 5 it is seen that each of the actors in the supply chain such as supplier, manufacturer, distributor, and customer send data from its transactions to the blockchain. In addition, the actors that manage the supply items communicate with each other with smart contracts. These smart contracts have been used for many forms of transactions such as buying and selling items, delivery and receiving items, etc. From Figure 5, it is seen that blockchain is the central communication pathway among relevant supply chain actors, which are interconnected through the smart contract.

In addition to added benefits of deploying blockchain-enabled smart contracts in the supply chain domain, there are also accompanying challenges to its widespread adoption. Some of the relevant challenges can be stated as regulations/legal issues, lack of standards and protocols, data privacy issues, error intolerance, lack of maturity in technology, etc., [136]. An additional challenge of deploying smart contracts in the supply chain is related to the huge issue concerning high-energy consumption, which increases the cost to support the supply chain use cases. For example, a PoW consensus algorithm such as PoS needs to be very energy-intensive that rises the supply chain cost significantly [137]. In such circumstances, it is noticed that smart contract is not suitable for all kinds of supply chains and their suitability mostly depends on certain scenarios as well as agreement type, scale, and scope within the supply chain operational processes.

7. Demo of Blockchain-Enabled Smart Contracts in Supply Chain

A typical supply chain starts with a supplier that transports component to a manufacturing site, which eventually site reach a customer via warehouse and transportation. Figure 6 illustrates the fundamentals of a typical supply chain process along with the flow of information as required to efficiently execute the process. In reality, supply chain management is a complex network, where multiple partners are involved at each production stage, raw materials are purchased from the upstream suppliers, processed, and transported to the final

products to the downstream customers. At each phase of the supply chain, necessary tracking of information is confirmed for smooth coordination among the phases. For instance, necessary information related to supplied components such as quality, price, specification, and quantity is needed to confirm between the phases of component supplier and transportation as displayed in Figure 6.

To track necessary information flow within various phases of the supply chain, a blockchain-enabled smart contract can be demonstrated. The purpose of this demonstration is to explore the key structures needed for maintaining a working blockchain-enabled supply chain operations. The daily operations in the supply network, such as transactions, components, quality, quality, etc., can be described step-by-step within the use of blockchain-enabled smart contracts. In addition, how each block within a blockchain is created and added along with various authentication functionalities such as PoW, timestamp, hash function, etc., are also provided. This lightweight demonstration uses Python language, but a similar solution could be implemented with any common programming language. Figure 7 displays the domain model of a blockchain-based class diagram using unified modeling language (UML) notations that contain the implementations of basic contents of the supply chain and logistics monitoring system.

Figure 8 provides the initial steps of the application. The blockchain implementation starts by defining the *Block* class, which defines the contents of each block and includes a method for calculating the hash object. The *Block* class will be used inside the *Blockchain* class for creating blocks. One block includes the following parameters: *index*, *transactions*, *timestamp*, *previous hash*, *nonce*, and *current hash*. An *index* is a sequential number starting from zero for the genesis block, *transactions* include any information that is stored in the blockchain, and *timestamp* saves the creation time of the block. *Previous_hash* stores the hash object of the previous block. This step links all the blocks together, as every new hash is now calculated with the previous hash as a block content, and changing the previous hash would change the whole chain after it. A *nonce* is short for “number used only once”. It is the number that is changed to alter the block contents. Changing any information in the block will also change the hash object. By changing *nonce*, the aim is to find a hash object calculated from the block contents that solve the condition explained later. Figure 8 also provides the details of the *hash_function* method in the *Block* class, which is used to encode the block contents as a hash object. It takes all the information in the block and encodes it into a series of characters. Our example uses the *sha256* function from the *hashlib* Python library to create an SHA-256 object that is transformed as a hexadecimal string.

Our implementation uses the *Blockchain* class, which contains all the essential methods for initiating a blockchain object and adding new immutable blocks. Figure 9 provides the details of the initialization of the blockchain object, which establishes a new blockchain object by creating an empty *chain* list and by creating a genesis block. The class cannot be used without generating a genesis block, as it will automatically be generated every time the object is initiated.

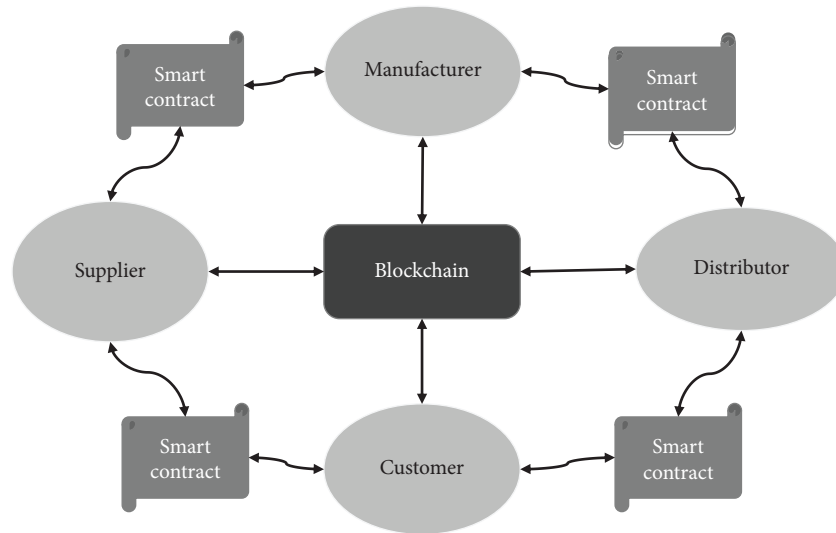


FIGURE 5: A framework of blockchain-enabled smart contracts in the supply chain.

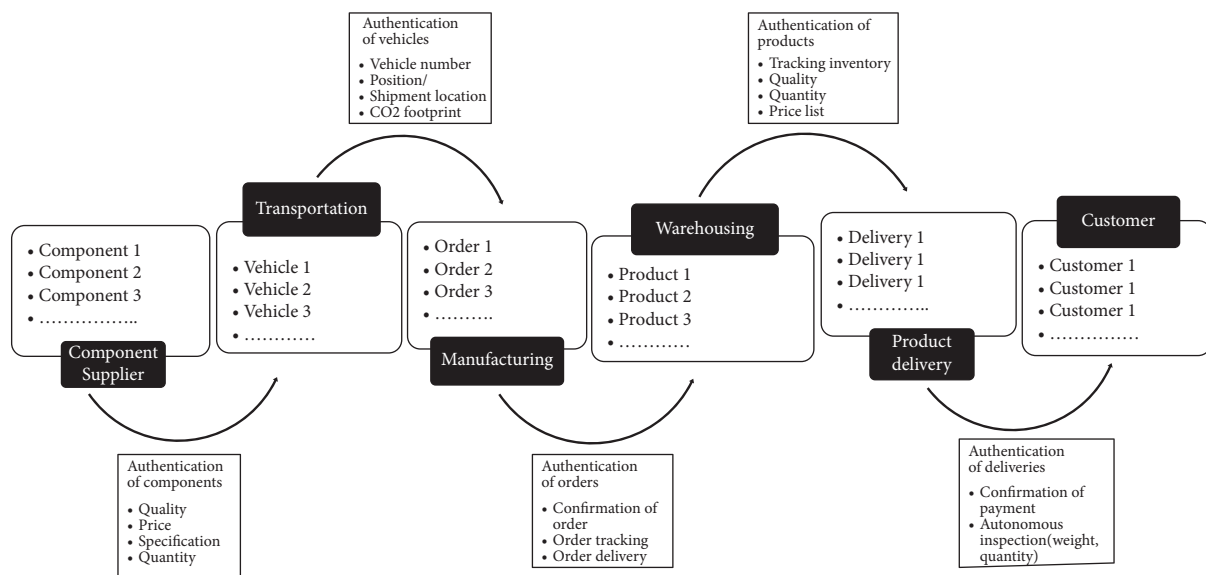


FIGURE 6: Fundamentals of a typical supply chain management system with necessary information flow.

The *genesis_block* method creates a block with index 0, empty transactions, current timestamp, and “0” for the previous hash, as the *Block* class is constructed so that a value for the previous hash is obligatory. After creating the *Block* object, the *genesis_block* method calls the *hash_function* method to compute a hash object for the genesis block and then adds it to the *chain* list that represents the blockchain.

Figure 10 provides the details of the method used to add transactions to a blockchain. The *add* method takes a transaction as an argument and returns the index number of the created block. How to define a transaction and use the method will be explained later. First, the method calls the *last_block* method of the *Blockchain* class, which will return the last block of the current chain. This is done to verify that

the new block continues the same chain. Then, the *Block* class is used to create a new *Block* object with the transaction and other necessary information (index, timestamp, and previous hash). Next, the method calls the *proof_of_work* function and gives it the new block as an argument. The *proof_of_work* function will alter the block contents by changing the value of the *nonce* argument, and calculating hash objects as long as needed to find the correct hash. The criteria for a correct hash can be, for example, a predefined number of zeros at the beginning of a hash string. The key is to define the criteria so that it will take a lot of computing power to search for the correct hash, making it impossible to alter the whole chain afterward. When the PoW is completed, the new block will be added to the chain, where once more, it is checked that the hash object is correct and the

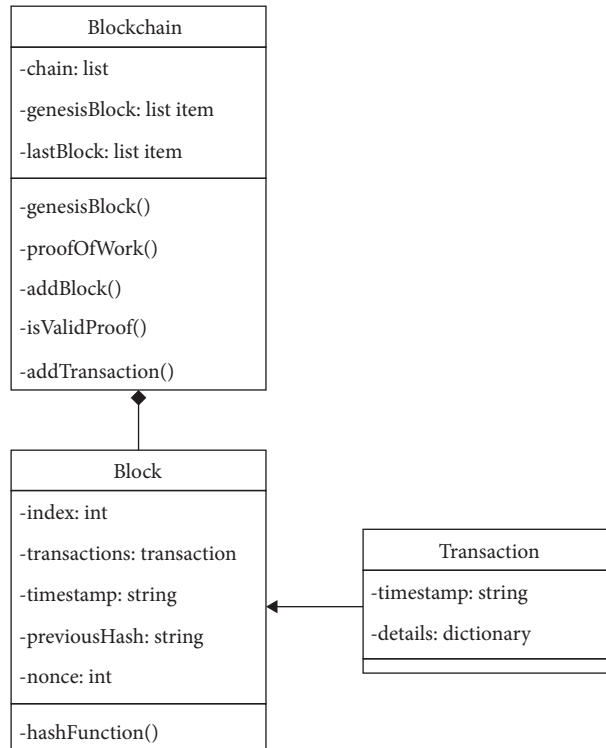


FIGURE 7: Domain model of blockchain-based supply chain class diagram using UML notation.

```

class Block:
    def __init__(self, index, transactions, timestamp, previous_hash, nonce=0):
        self.index = index
        self.transactions = transactions
        self.timestamp = timestamp
        self.previous_hash = previous_hash
        self.nonce = nonce
    def hash_function(self):
        block_string = json.dumps(self.__dict__, sort_keys=True)
        return sha256(block_string.encode()).hexdigest()
  
```

FIGURE 8: The code for creating a 'class block' for a blockchain.

```

class Blockchain:
    def __init__(self):
        self.chain = []
        self.genesis_block()
    def genesis_block(self):
        genesis_block = Block(0, [], time.time(), "0")
        genesis_block.hash = genesis_block.hash_function()
        self.chain.append(genesis_block)
  
```

FIGURE 9: The code for creating a 'genesis block' for a blockchain.

previous hash object of the new block matches the chain. If everything matches correctly, the block is permanently added to the chain.

The Blockchain class also includes methods for calling the last block, PoW, adding a new block, and checking PoW validity. The purpose of these methods is evident, and the

```

def add(self, transaction):
    last_block = self.last_block
    new_block = Block(index=last_block.index + 1,
                      transactions=transaction,
                      timestamp=time.time(),
                      previous_hash=last_block.hash)
    proof = self.proof_of_work(new_block)
    self.add_block(new_block, proof)
    return new_block.index

```

FIGURE 10: The details of the add method in the blockchain class, which is used to add new immutable blocks to a blockchain.

```

Component_supplier = {
    'transactions': [
        {
            'timestamp': time.time(),
            'quality': '1st class',
            'serial number': '0001',
            'name': 'Component',
            'quantity': 100,
        },
        {
            'timestamp': time.time(),
            'quality': '1st class',
            'serial number': '0002',
            'name': 'Component',
            'quantity': 100,
        }
    ]
}

```

FIGURE 11: An example of a component supplier's transactions within the blockchain.

```

transportation = {
    'transactions': [
        {
            'timestamp': time.time(),
            'vehicle number': 1,
            'shipment location': 'City 1',
            'CO2 footprint': '307 g'
        },
        {
            'timestamp': time.time(),
            'vehicle number': 2,
            'shipment location': 'City 1',
            'CO2 footprint': '155 g'
        }
    ]
}

```

FIGURE 12: An example of the transaction details for shipping.

details of the code for these methods are omitted. To add transactions to the blocks, we must first define the transaction contents. As discussed, the transaction contents are provided as an argument to add method of the Blockchain class (see Figure 10).

Figure 11 presents an exemplary transaction from the component supplier. In our example, transactions are added to the chain as Python dictionaries. The transaction includes shipping units of two components, which are both quality-checked by the supplier. The transaction includes

```

manufacturing = {
  'transactions': [
    {
      'delivery time': time.time(),
      'order number': 1,
      'signature': 'Approved',
      'order status': 'delivered'
    },
    {
      'delivery time': time.time(),
      'order number': 2,
      'signature': 'Approved',
      'order status': 'delivered'
    }
  ]
}

```

FIGURE 13: An example of the transaction details for manufacturing.

```

warehousing = {
  'transactions': [
    {
      'timestamp': time.time(),
      'product': 1,
      'quality': '1st class',
      'quantity': 60,
      'price': 100
    },
    {
      'timestamp': time.time(),
      'product': 2,
      'quality': '1st class',
      'quantity': 40,
      'price': 1000
    }
  ]
}

```

FIGURE 14: An example of the transaction details for product warehousing.

a timestamp to verify the transaction time. Now that the transaction is defined, it can be added to the blockchain by calling the *add* method and adding the *Component_supplier* dictionary to it as an argument. After the transaction is added and a new block is created, the information is permanent.

An exemplary transaction by the transporting company is shown in Figure 12. The transportation company has gotten the shipping items from the component supplier and is now adding the transportation details to the chain. The transaction includes two shipping vehicles. The transportation company tracks and reports the carbon footprint of each vehicle for easier calculation of the products' environmental impact.

Figure 13 displays an exemplary transaction inputted by the manufacturer. The transportation company has delivered the components, and the manufacturer is now confirming the shipping of the items. The transaction includes two orders. The manufacturer confirms that the shipped items are intact and delivered. As the signature and order status are updated to the chain, the information is permanent. This prevents future product quality disputes since quality control is

confirmed at each phase of the supply chain, and all parties confirm that the items are intact and of the required quality.

An exemplary transaction for product warehousing is displayed in Figure 14. The transaction includes units of two products received from manufacturing to be stored until they are sold to the customer. The warehouse confirms another quality check and product quantity and price.

An exemplary transaction for product delivery is displayed in Figure 15. The transaction includes the delivery of two product units. The customer has ordered the products, and the order quantity and payment are confirmed before the delivery can begin.

Figure 16 displays the python code for adding the transactions and creating new blocks to the blockchain. As explained before, a new blockchain is created by initiating a blockchain object using the *Blockchain* class. Then, a new block is added by calling the “add” method. The add method takes the transaction dictionary as an argument and starts the PoW process to create a new permanent block with a unique hash function.

Figure 17 displays the first three blocks of an exemplary blockchain for one supply chain. The “get_chain” method

```

productDelivery = {
  'transactions': [
    {
      'timestamp': time.time(),
      'Payment': 'Approved',
      'product': 1,
      'quantity': 3
    },
    {
      'timestamp': time.time(),
      'Payment': 'Approved',
      'product': 2,
      'quantity': 15
    }
  ]
}

```

FIGURE 15: An example of the transaction details for product delivery to the customer.

```

blockchain = Blockchain()
blockchain.add(componentSupplier)
blockchain.add(transportation)
blockchain.add(manufacturing)
blockchain.add(warehousing)
blockchain.add(productDelivery)

```

FIGURE 16: Python code for initiating the blockchain and adding the transactions.

```

blockchain.get_chain()
Blockchain:
[0
[]
1648195819.548159
3196f65dfd6cee30a57d4be4e72bede96d9510d4e7f3792062ac2006c1a5e086]
[1
{'transactions': [{'timestamp': 1648195805.7770144, 'quality': '1st class',
'serial number': '0001', 'name': 'Component', 'quantity': 100},
{'timestamp': 1648195805.7770141, 'quality': '1st class', 'serial number': '0002',
'name': 'Component', 'quantity': 100}]}
1648195865.633855
0002173c87e6b09bd7d12cd20190117a30649bf3be0da9a2ba7eac49fc7f575e]
[2
{'transactions': [{'timestamp': 1648195805.7770144, 'vehicle number': 1,
'shipment location': 'City 1', 'CO2 footprint': '307 g'}, {'timestamp': 1648195805.7770141,
'vehicle number': 2, 'shipment location': 'City 1', 'CO2 footprint': '155 g'}]}
1648195865.777814
00020431db991e3592ce04bd96376161c4afd4f4af2765ac2d7909580417554]

```

FIGURE 17: Observing the contents of the blockchain for an exemplary supply chain.

prints the full blockchain for easier observation. The blocks now display the transactions added in the previous phases. In addition, the blocks include a timestamp for the exact time that the block was created and the hash function. In this

demonstration, the hash function was required to begin with three consecutive zeros (PoW). Figure 18 provides a framework depicting the blockchain implementation in supply chain for traceability. From Figure 18, it is seen that each of

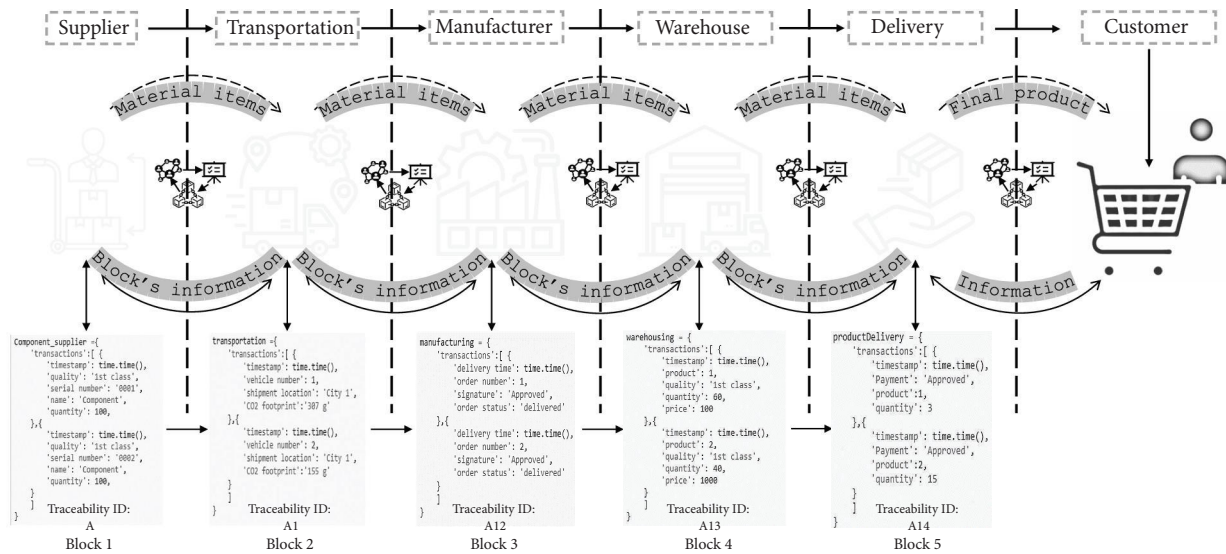


FIGURE 18: A framework depicting the blockchain implementation in supply chain for traceability.

the supply chain stakeholders are connected by blocks to maintain the integrity among them that contributes to ensure transparency among the supply chain stakeholders.

8. Conclusions and Future Works

The supply chain and logistics/shipping industry require immense data transparency and traceability since several independent entities are involved and there is a clear lack of transparency due to complex processes and different roles of middlemen [9]. The engaging parties coordinate with each other through several different channels such as emails, phone calls, etc. and the data is stored in several separate systems that might result in the ineffectiveness of tracking shipment [138]. Therefore, a self-governing system providing several layers of trust, effectiveness, and transparency is needed to deal with such a complex process of the global supply chain and logistics ecosystem.

As blockchain keeps a distributed and decentralized record of digital transactions, it offers a real-time and secured system for information sharing, and developing integration in several ways in different sectors [139]. The core purpose of blockchain in the supply chain is to bring transparency through efficient and timely transactions [134], real-time information, reliability, and visibility. Blockchain is enabling radical innovations by providing unprecedented transparency opportunities and technology solutions across all industries' SCs; thus, various efforts to tackle such enriched flow of data and to transform into a new ecosystem of developed capabilities and designing/redesigning business models—the digital business ecosystem—are occurring [8].

This paper contributes to explaining the fundamental concept of blockchain technology and highlighted various opportunities that can be achieved from it, especially in the supply chain domain. It provides a comprehensive definition of blockchain technology in the context of

supply chain management by conducting a content analysis-based literature review. It also identifies the possible impacts of blockchain in the case of supply chain transparency. In addition, it proposes a conceptual framework to interpret the relationships between blockchain and smart contracts for the supply chain management. Moreover, this study not only highlighted the accompanying benefits of blockchain in the supply chain but also identifies the different barriers or challenges to the deployment of blockchain technology in various supply chain domains. Furthermore, this study contributes by providing a demo of how blockchain technology can be programmed and deployed to ensure the transparency of the supply chain stakeholders.

In the future, this study can be extended to investigate how blockchain technology can improve the supply chain maturity level and sustainability. In addition, this study also can be extended to validate the smart contract demo by deploying the procedure steps in real-life case examples. Moreover, future studies can be orchestrated to identify additional challenges to deploying blockchain in the supply chain, which would act as the motivation for future research in this domain. Furthermore, the study can be focused on maintaining a balance between privacy and security to manage global supply networks.

Data Availability Statement

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Conflicts of Interest

The authors declare no conflicts of interest.

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